Original Article

Extreme Heat Kills Even in Very Hot Cities: Evidence from Nagpur, India

Priya Dutta[1], Lm Sathish[1], Dileep Mavankar[1], Partha Sarthi Ganguly[1], Sujata Saunik[1]

[1]Indian Institute of Public Health Gandginagar, Gandhinagar, India

Abstract

Background: Although many studies have provided evidence for all-cause mortality attributed to extreme temperature across India, few studies have provided a systematic analysis of the association between all-cause mortality and temperature.

Objective: To estimate the risk associated with heat waves during two major heat waves of Nagpur occurred in 2010 and 2014.

Methods: The association between temperature and mortality was measured using a distributed lag non-linear model (DLNM) and the attributable deaths associated with the heat waves with forward perspective in the DLNM framework.

Results: From the ecological analysis, we found 580 and 306 additional deaths in 2010 and 2014, respectively. Moving average results also gave similar findings. DLNM results showed that the relative risk was 1.5 for the temperature above 45 °C; forward perspective analysis revealed that the attributable deaths during 2010 and 2014 were 505 and 376, respectively. Results from different methods showed that heat waves in different years had variable impacts for various reasons. However, all the results were consistent during 2010 and 2014; there were 30% and 14% extra-mortalities due to heat comparing to non-heat wave years.

Conclusion: We strongly recommend the city Government to implement the action plans based on this research outcome to reduce the risk from the heat wave in future.

Keywords: Mortality; Weather; Hot temperature; Climate change; Global warming; Heat stroke; India

Introduction

Extreme summer temperature and frequent heat wave are important public health issues globally.[1] Major heat waves in the North America, Europe, Korea, Asia, and Australia have caused significant increases in premature mortality.[2-7] However, in India from the year 1992 to 2015, heat waves have caused 22 653 officially reported deaths that also includes more than 2500 deaths in historically deadliest heat wave of India during summer of 2015.[8] In May 2010, we observed a deadly heat wave in Ahmedabad with a peak temperature of 47 °C on May 21, resulting in over 300 deaths in one day and an extra death toll of 800 deaths in one week. Following this, the Indian Institute of Public Health Gandhinagar (IIPHG) supported by the Natural Resources Defense Council (NRDC) helped the Ahmedabad Municipal Corporation (AMC) to launch the heat action plan in Ahmedabad

Correspondence to Priya Dutta, MD, Indian Institute of Public Health-Gandhinagar (IIPHG), Opp. Airforce Head Quarters, Gandhinagar - Chiloda Road, Gandhinagar – 382042, Gujarat, India
Tel: +91-940-864-3559
E-mail: priya.iiphg@gmail.com
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city in April 2013. This was the first such preparedness plan for extreme heat events in South Asia.[9]

According to a recent study conducted by India's two premium meteorological institutes, the Indian Meteorological Department (IMD), and the Indian Institute of Tropical Meteorology (IITM), the average heat index in India is significantly increasing at a rate of 0.56 and 0.32 °C/decade in summer and monsoon, respectively. This increasing trend of heat index was observed in almost all the regions of India for the last 60 years—1951 to 2010.[10] Considering the spatial pattern of heat index, maximum temperature and humidity across India, scientist concluded that there is a greater chance of heat illness in the southeastern coastal regions like Andhra Pradesh, Orissa, and Tamil Nadu in summer and over northwestern regions like Rajasthan and Indo-Gangetic plains in monsoon.[10] Comparing all India annual, seasonal mean (maximum and minimum) and diurnal temperature, Jaswal, *et al*,[11] concluded that the average annual mean maximum and minimum temperature is increasing at a rate of 0.05 °C/decade, but found no trend in annual diurnal temperature. The uneven changes in diurnal temperature are due to higher increase in the mean maximum and minimum temperature.[11]

Excessive heat is measured relative to local temperatures and weather condition, which could be a reason why the definition of a heat wave varies from location to location.[12] Yet, a large body of evidence suggests that climate change is fueling longer, more intense, and in many cases, more widespread heat waves.[13] Urban health risks during heat waves have increased significantly because the sprawling urban growth intensifies the urban heat island effect by 3–12 °C relative to the surrounding rural areas.[14,15]

The public health threats posed by extreme heat during heat waves affect cities globally, yet can be especially challenging in countries like India where millions of highly heat-vulnerable residents also have low adaptive capacity; limited access to air conditioning and frequent power outages in summer months can interrupt air conditioning service when it is most needed. Therefore, it is important to develop heat-health action plans that include local early warning systems to alert the community, municipal corporation and other government agencies, electronic and social media, and health practitioners of approaching heat waves in advance. The lessons from Ahmedabad heat action plan have been scaled to few cites/states of India like Vidarbha Region in Maharashtra, Odisha state, Hyderabad, and Surat.[9]

Nagpur has experienced extreme heat in recent years, often with a corresponding increase in mortality. Nagpur is also among the Indian cities now developing its own heat action plan, by adapting Ahmedabad's heat action plan for its own population, local conditions and needs.[9]

We conducted this study to estimate the impact of recent heat wave in 2010 and 2014 and identify the relationship of all-cause mortality with maximum temperature and its effect in Nagpur city. These findings can better help the implementation of the Nagpur District's new regional heat action plan that launched in March 2016.

Materials and Methods

The Nagpur Municipal Corporation (NMC) records daily mortality data from the entire city area from all hospitals, crematoria and burial grounds. No human bodies can be disposed within the city without registration of death. Government and private sector hospitals report deaths that occur in their premises; heads of families report deaths which happen at home or places other than hospital to the crematorium or burial ground clerk; the information is then provided to municipal corporation office in their respective zones. Then the data are analyzed by the Registrar of Births and Deaths (RBD) Department of the NMC office after three weeks (statutory period for reporting). We acquired daily all-cause mortality data from the Registrar of Births and Deaths (RBD) Department for our research from 2009 to 2015.

Daily temperature (maximum, minimum) and relative humidity data were obtained from the Indian Meteorology Department's at district level for the respective years 2009 to 2015. Therefore, we are using only secondary data with formal approval from NMC and IMD.

This study focuses on Nagpur, Vidharbha region of Maharashtra, India with over 3.1 million people living in its urbanized areas, making it the third largest city in Maharashtra state.[16] Nagpur's summer months of March through May have relatively low humidity, although hot weather can continue through June, with daily maximum temperatures exceeding 45 °C. The month of May is typically Nagpur's warmest month; during the period 1969–2010, daily maximum temperature of May averaged 42.7 °C; the daily minimum temperature averaged 27.8 °C.[16]

TAKE-HOME MESSAGE

- Few studies have provided a systematic analysis of the association between all-cause mortality and temperature.
- We assessed two heat waves occurred in 2010 and 2014 in Nagpur, India.
- Exposure to maximum temperature after a certain threshold is associated with a higher mortality risk.
- The relationship between high and low temperature at the regional level is responsible for increase in morality.

To explore the effects of the 2010 and 2014 heat waves on mortality rates in Nagpur, we performed an ecological analysis to understand the preliminary relationships between daily all-cause mortality and maximum daily temperature in the city. Due to unprecedented heat waves, we chose May 1–31, 2010, and May 15–June 15, 2014, as the study period. We calculated 7-day moving average of each day in May 2010 and 2014; we then compared them to average values from 2009 and 2011 and 2012 and 2013, respectively, a methodology similar to Cohen, *et al* (2017).[17]

We compared the death counts in May 2010 with May 2009, and that in May 2014 with May 2011. Usually, these years were chosen to control various factors like population size, demographic characteristics, and ecological levels. The excess all-cause deaths are calculated as the difference between the total monthly deaths recorded in May 2010 and 2014 minus the total reference period death counts recorded for May 2009 and 2011 and May 2012 and 2013, respectively, again using an averaging method and 7-day moving average method as described above. Percentage increase in May 2010 and 2014 monthly extra mortality was also estimated relative to 2009 and 2011, and 2012 and 2013, respective reference period.

Ethics

The study was approved by Indian Institute of Public Health ethical committee.

Statistical Analysis

The DLNM framework was used to estimate the temperature-mortality association for 2010 and 2014 heat waves separately.[18] We did the statistical analysis with *R* ver 3.6 using the package *dlnm*.[19] We fitted the time series quassi-Poisson regression model, allowing for over-dispersion and controlling for day of the year and relative humidity, using a 3 df/year spline.

Table 1: Daily number of all-cause mortality and maximum temperature in °C during the heat wave period of summer 2010 and 2014 in Nagpur, India

	Standard analysis			Moving average	
Variable	**2010, mean (SD)**	**Average for 2009 and 2011, mean (SD)**	**Excess in 2010, n (%)**	**Average for 2009 and 2011, mean (SD)**	**Excess in 2010, n (%)**
May 1–31, 2010					
Total deaths	2513	1934	580 (30)	1918	595 (31)
Daily mortalities	81.1 (28.5)	62.4 (9.9)	18.7 (30)	62	19.06 (31)
Maximum temperature (°C)	44.3 (2.2)	43.5 (1.6)	0.8 (2)	—	—
Minimum temperature (°C)	29.3 (2.1)	28.1 (1.7)	1.2 (4)	—	—
Variable	**2014, mean (SD)**	**Average for 2012 and 2013, mean (SD)**	**Excess in 2014, n (%)**	**Average for 2012 and 2013, mean (SD)**	**Excess in 2014, n (%)**
May 15–June 14, 2014					
Total deaths	2450	2144	306 (14)	2138	312 (15)
Daily mortalities	81.7 (21.4)	71.5 (10.3)	10.2 (14)	69	12.7 (18)
Maximum temperature (°C)	43.5 (2.3)	43.6 (3.0)	-0.1	—	—
Minimum temperature (°C)	27.8 (2.9)	29.4 (2.9)	-1.6	—	—

We selected the cross-basis function *a priori* to represent the association between the daily maximum temperature and daily all-cause mortality. The cross-basis is composed of a quadratic B-spline with two knots at 42 and 44 °C, respectively, for the maximum temperature for 2010 centred at 42 °C, and for 2014 centred at 41 °C. We used the codes from attributable risk from distributed lag to compute the attributable deaths using forward perspective approach.[18]

Results

Table 1 shows the distribution of daily all-cause mortality data for heat wave period of 2010 (May 1–31, 2010) and 2014 (May 15–June 14, 2014) of Nagpur city. The data set included 4971 all-cause deaths during 2010 and 2014 summer months. The mean daily mortality during the heat wave period of 2010 and 2014 was 81.1 (SD 28.5) and 81.7 (SD 21.4) deaths/day, respectively, which was significantly higher than the average during the reference period—62.4 (SD 9.9) deaths/day for 2010, and 71.5 (SD 10.3) deaths/day for 2014. This showed an additional all-cause mortality of 580 deaths in May 2010 and 306 deaths in May 15–June 15, 2014—an increase of 30%, and 14%, respectively, above the reference period.

The summer mean maximum temperature was 44.3 (SD 2.2) °C for 2010; it was 43.5 (SD 2.3) °C for 2014. The mean minimum temperature for 2010 and 2014 was even 29.3 (SD 2.1) and 27.8 (2.9) °C, respectively, which was higher than the reference year (Table 1).

In addition, the 7-day moving average method of daily all-cause deaths showed

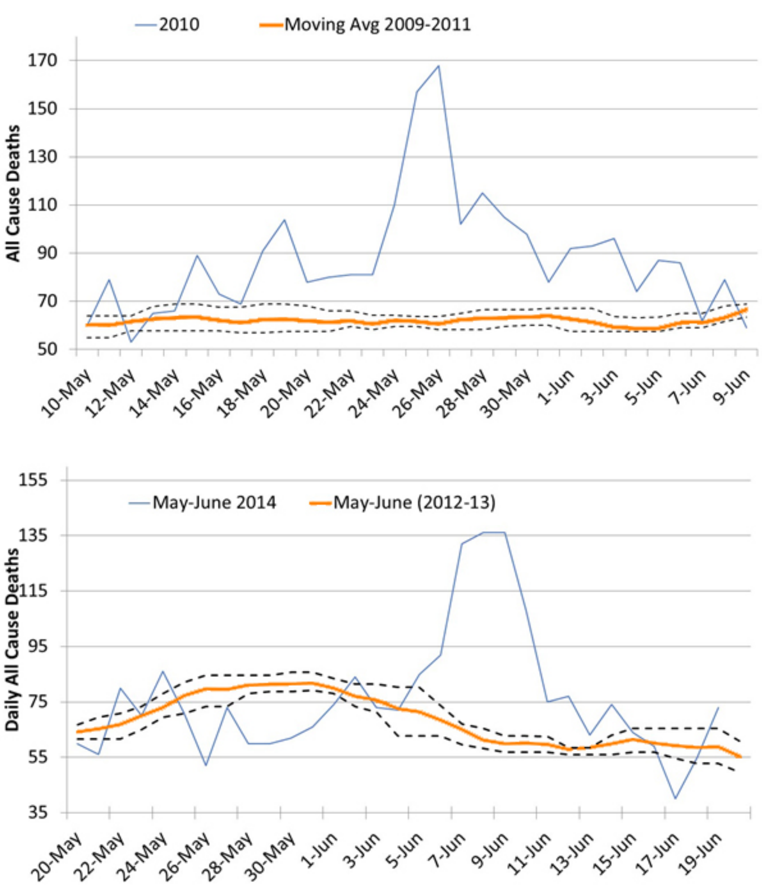

Figure 1: Top panel) daily number of all-cause deaths in May 2010 heat wave with corresponding days in 2009 and 2011. Bottom panel) daily number of all-cause deaths in May–June 2014 heat wave with corresponding days in 2012 and 2013. The orange solid lines are moving average; dashed lines represent interquartile range of the moving average.

around 595 deaths (31% increases) in summer 2010, and 312 deaths (15% increase) in summer 2014. The results further depicted over 30% excess deaths during May 2010 and 15% extra deaths in 2014. Figure 1 shows the findings of the daily mortality counts of May 2010 and mid-May to mid-June 2014 with the average of the same months in 2009 and 20011, and 2012 and 2013.

For calculating the extreme heat period, we used the week of May 19–25, 2010. According to the IMD's heat wave definition of daily maximum temperatures, when temperature is above 45 °C from the normal so, we included an acute 4-day extreme heat period from May 20–23, 2010 as the extreme heat wave period (H). The effective reference period (R1) is considered the immediately preceding period from May 12–18, 2010 and the alternative reference period (R2) of May 19–25 to the year before 2009 and after 2011. The relative risk (RR) was calculated for both reference periods R1 and R2. We assumed that the population size during our study period had minimal changes and cancelled the person-time units from the numerator and denominator. The simplified RR was calculated using the formula RR = H/R.[20,21]

The RR of mortality was 1.559 (95% CI 1.452 to 1.673) compared to a reference period (R1) in the preceding week from May 12–18, 2010, and the alternative reference period (R2) of May 15–June 3 from 2009 and 2011. A moderate-to-high correlation was observed between monthly total all-cause deaths and monthly maximum temperature during summer. The mean and median daily mortality in summer 2010 were 69 and 65 (IQR 22), respectively; the respective values for May 2010 were 81 and 78.

Using the distributed lag non-linear model (DLNM), the association between temperature and all-cause mortality for the years 2010 and 2014 is shown in Figure 2. The effect of high temperatures on mortality was expressed as the RR of daily mortality for increases in max temperature for the entire range in the summer months of both studied years.

The association between temperature and all-cause mortality are presented as RR, with the centering point at 42 °C for 2010 and 41 °C for 2014 (Fig 2). With increasing temperature, the curve increases in both studied years. For the year 2010, when the temperature is above 95th percentile, the RR is 1.5 and reaches its maximum of 1.8 at the maximum temperature of 47.3

°C; similar trend can be seen for 2014.

Additional fraction of deaths due to increase in temperature was estimated by combining the risks on the given and previous days (forward perspective) also known as attributable fraction (AF), according to the pre-defined lag window (0–21). The daily additional number of deaths (AD) was calculated by multiplying the daily AF by the daily number of deaths. From the model, centered at 42 °C, the total additional deaths attributable to the heat wave for the year 2010 was 505. For the year 2014, centered at 41 °C, the total number of additional deaths was 376.

Discussion

Globally, studies have raised public health concern regarding the relationship between increasing temperature and mortality. This is a proven fact that exposure to maximum temperature after a certain threshold is associated with a higher mortality risk. Our study revealed an association between heat wave and all-cause mortality during two major heat wave of Nagpur in 2010 and 2014. We used smoothed 7-day average calculation as well as the ecological analysis to calculate the baseline mortalities occurring during the May 2010 heat wave. The estimated mortality in Nagpur had a 30% increase when compared with the same period of other years. Therefore, an additional 595 deaths occurred in the city during 2010 heat wave period which was over 30% extra deaths. The attributable deaths calculated was 505, based on DLNM, which means that during 2010, at least 500 additional deaths occurred due to heat.

In 2014, the heat wave occurred in the late summer, the first week of June; for its lateness, the impact was lesser than that in 2010. However, the additional deaths were 306, 312, and 376, based on the ecological analysis, moving average method, and attributable risk derived from the DLNM, respectively. So, at least 300 deaths occurred during the 2014 heat wave—a 14% increase compared to reference periods.

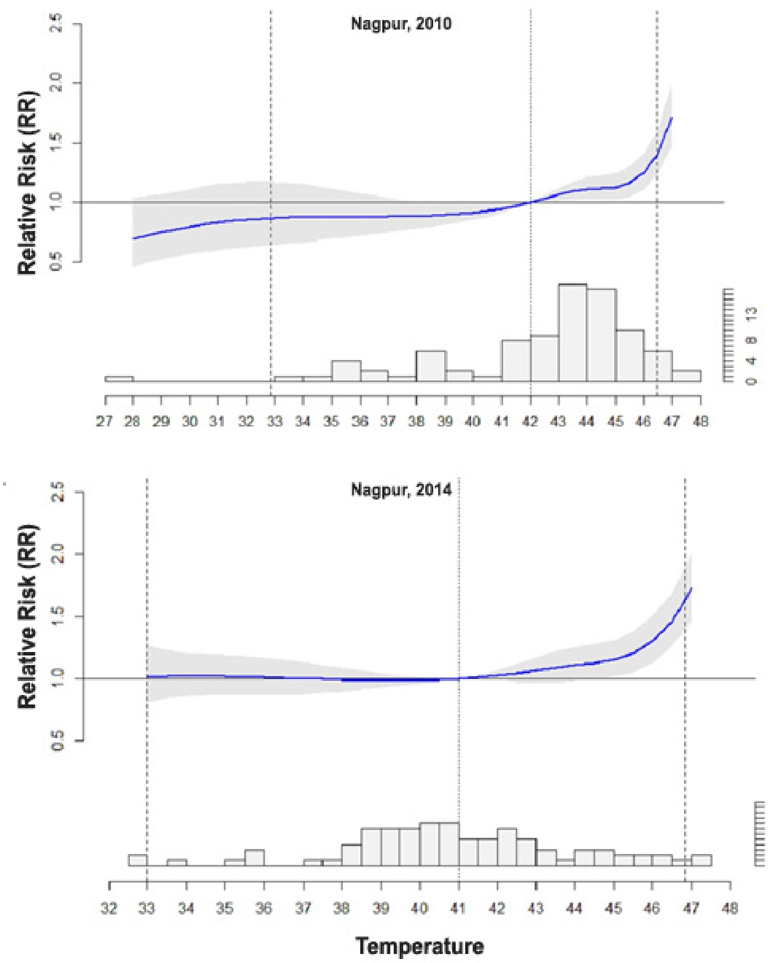

Figure 2: Relationship between temperature and all-cause mortality in Nagpur during summer. Top panel) the overall cumulative response and exposure associations with temperature distribution in summer 2010. Bottom panel) overall cumulative response and exposure associations with temperature distribution in summer 2014. Dotted and dashed vertical lines represent the cut-off values for defining the extreme heat.

Previous studies have shown that exposure to extreme high temperature is associated with increased all-cause mortality and morbidity and health outcomes like cardiovascular and respiratory diseases and heat-related diseases like heat stroke and dehydration. The cause-specific mortality is usually exacerbated by extreme heat and progresses to premature mortality.[20,21] Our study findings were in keeping with the results of previous studies.

Our analyses showed several notable findings. Most importantly, our results revealed that the relationship between high and low temperature at the regional level is responsible for increase in morality. We assessed two heat waves occurred during the last decade—in 2010 and 2014. We tried to establish a relationship between extreme high temperature and all-cause mortality in Nagpur city. It is necessary to understand that the RR was derived based on the length and intensity of the heat waves and local acclimatization to the past heat waves. It can clearly be seen that the combination of increased maximum and minimum temperature in a day has more impact on death tolls. We believe that the minimum temperature has also an important effect on the mortality. Days with higher maximum temperature had higher minimum temperatures too.

Based on the model presented, we can provide a cut-off temperature for Nagpur above which an alert should be triggered during summer—temperatures above 45 °C (the 95th percentile) increases the RR by 50%, so we need to issue a red alert.

Our study has several limitations including classification of the nature of death, occupation and location of death in our study subjects. Mortality data reporting is not uniform across the nation; in most instances, even the location or address, occupation and age of the deceased person are not tractable. However, we studied risks associated with heat waves during two major heat waves of Nagpur for the year 2010 and 2014, and we assumed that these issues have not affected during the study period. We have adjusted our model for possible confounding variables like population and time lags.

Since we only considered the heat wave years in our study, it will be a good idea to compare the findings with those obtained from more years to see if any trends exist in heat waves. Also, we need to see the spatial variations and age-wise classifications to find groups more vulnerable to heat waves. From our previous experience in the city of Ahmedabad, we strongly believe that heat action plans can help in reducing the impact of heat waves. We are expecting more heat waves in coming years. To combat these deadly events, we need to be prepared and implement more action plans at both the national and regional levels.

Conflicts of Interest: None declared.

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