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A Tale of Five Cities: Heat Waves, Cold Spells and Mortality Risk in Urban India
Heat, Cold Extremes and Mortality in India

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Abstract

Background: *Temperature extremes as a consequence of changing climate are known to have large morbidity and mortality impacts. Studies assessing mortality risk due to heat waves and cold spells are largely absent in urban India. Addressing this gap is critical in developing adaptation measures to protect the health of vulnerable populations in urban India.*

Methods: *Daily all-cause mortality, temperature and humidity data were collected for five cities – Ahmedabad, Bangalore, Hyderabad, Mumbai and Shimla spanning 2005 - 2012. We developed Poisson regression models to study 'the main temperature effect' as well as 'additional impacts' of sustained high and low temperatures (i.e. heat and cold waves) on all-cause mortality risk.*

Results: *We find large heterogeneity among mortality risks across urban areas. Typically, risks increase with intensity of heat (cold) waves. Populations in hotter environments may be more susceptible to cold related impacts and vice-versa. Across urban areas the main temperature effect captures most of the mortality risk. We find that 'additional impacts' due to sustained temperatures (heat and cold waves) is not significant.*

Conclusions: *This is one of the first multi-city studies to examine mortality risk due to heat and cold waves in Indian cities that are spread across climatic regions and topographies. Our findings highlight the need for developing planned adaptation measures in Indian cities to minimize health impacts.*

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Introduction

A large number of studies, primarily in developed country settings, show that temperature extremes (heat and cold) are related to adverse health outcomes[1–5]. A changing climate has heightened the risk of temperature related morbidity and mortality, globally. For instance, studies of recent heatwaves across Greece in 2007[6], Australia in 2009[7], Russia in 2010[8] and US in 2012[9] were all associated with increased mortality.

The latest assessment (AR5) by the Intergovernmental Panel on Climate Change finds that health risks related to temperature extremes are likely to increase in future[10]. Climate models project that frequency and intensity of heatwaves is set to increase irrespective of emission scenarios upto the year 2040[11]. This implies that study of impacts related to temperature extremes is critical to developing planned adaptation responses in the short term.

Multiple studies, suggest that average as well minimum and maximum temperatures in India are expected to increase in the future[12]. India has experienced a series of heatwaves in the past[13] that reveal their significant mortality impacts. For instance, in the year 1998, the state of Orissa faced an unprecedented heat wave situation as a result of which 2042 people lost their lives[14]. In another instance, 1421 people were killed in Andhra Pradesh from a heat wave in 2003[15]. More recently, 1344 excess deaths were recorded during the 2010 heat wave for the city of Ahmedabad[16].

The need for adaptation measures is more acute in developing country settings as they may be more vulnerable to a changing climate. A large population in Indian cities are people who are forced to live in conditions of deprivation - without adequate shelter; lack of sanitation and hygiene; lack of proper employment and lack of access to health facilities. Very often their work conditions require them to work outdoors for prolonged time periods, thereby exposing them to temperature extremes. However, studies examining the mortality risks of temperature extremes in urban India are largely absent.

In this study we estimated the mortality risks associated with heat waves as well as cold spells in five urban areas in India for the period 2005 to 2012. In addition to the independent effects of high (low) temperatures, we determined the additional risks due to sustained duration of heat (cold) on mortality.

Methods

We collected data on daily all-cause mortality, minimum and maximum temperature, relative humidity and pollution for the cities of Ahmedabad, Bangalore, Hyderabad, Mumbai and Shimla from 2005 to 2012. Mortality information was collected from the death registers of the respective municipal corporations. Weather data was collected from the Indian Meteorological Department (for details see supplementary information).

The rationale for choosing these cities was that they are each representative of a different climatic zone. In addition to climatic zone, these cities represent varied topography – plains, plateau, coastal areas and hilly regions. Though climate change is a global phenomenon, its impacts are local in nature and are likely to vary across cities and climatic zones. Therefore, cities were selected such that they broadly represent varying vulnerability to climate change related impacts. The approach of selecting one city from each climatic zone gives us an insight into how climate change impacts are likely to vary across India.

Defining heat waves and cold spells

Although there is no universally accepted definition, heat and cold waves are understood to be extended periods of extreme temperature[17]. We carried out an analysis of heat and cold wave effects using the Indian Meteorological Department (IMD) definition as well as the approaches used in literature. Heat waves were defined as two or more consecutive days where the daily maximum temperature exceeds 97th, 98th or 99th percentile of the summer temperature distribution for that given city. Cold waves were defined as duration of two or more consecutive days where the daily minimum temperature was lower than the 1st, 2nd or 3rd percentile of the winter temperature distribution for that given city.

The IMD defines a heat wave based on the 'normal' temperature for a given weather station. The 'normal' temperature is a long term average of daily recorded temperature values for that station. If a station's normal temperature is less than 40°C, an increase of 5 to 6 degrees above the normal temperature is considered as a heat wave. For stations whose normal temperatures exceed 40°C, an increase of 3 to 4 degrees above the normal temperature is considered as a heat wave [18].

Similarly, the IMD definition of cold wave is based on the wind chill temperature. For any given station with normal temperature above 10°C a decrease of -5°C to -6°C is below normal is considered as a cold wave. For stations whose normal temperature is below 10°C a decrease of -4°C to -5°C is considered as a cold wave[18]. Since, no wind speed measurements were available; IMD definition for cold wave was not included in this analysis.

Modelling Paradigm

Within a semi-parametric regression framework, the model used to study the association between mortality and temperature extremes can be expressed as

$$Log[E(Y_{ij})] \quad = \quad \sum_{j=1}^{P} g(x_{ij}) + DOW + \alpha W_{ij} + \varepsilon \qquad \ldots(1)\ldots$$

where Y_{ij} is the daily number of deaths for the i^{th} city on the j^{th} day and is assumed to follow an over-dispersed Poisson distribution. The covariates x_{ij} represent daily temperature, relative humidity and time for the i^{th} city on the j^{th} day. The effects are expressed by an unknown smooth function g constructed using natural cubic splines. An indicator variable for each day of week is given by *DOW*. W_{ij} is an indicator variable that captures the added risk of mortality heat or cold wave for the i^{th} city on the j^{th} day. This variable takes value “0” on non-heat/cold wave day and 1^{st} day of a heat/cold wave; value "1" on second day of heat/cold wave; "2" if it is the third day of the wave and so on. The parameter α represents the log relative risk of mortality on a heat (or cold) wave day. The error term is modelled using ε.

The temperature variable was modelled using natural cubic splines with three degrees of freedom. To account for delayed effects, we used lagged values of 20 days for temperature. A smooth function with 2 degrees of freedom was used for the lag. This formulation provides the flexibility required to capture added risk associated with heat or cold waves in addition to temperature related effects[19]. The exponential of the estimate (alpha) in equation (1) gives the added relative risk of mortality on a heat (or cold) wave day[2].

A natural spline with four degrees of freedom for humidity was used. Seasonal and long term trends in data were controlled for using a smooth function of time with seven degrees of freedom per year. This representation has been used is most of the recent studies[1,20]. This is equivalent to a two month moving average and is thought be a good balance between removing long term trends while leaving enough variation to capture short term temperature-mortality relationships[21]. There is no consensus on the representation of unmeasured confounders although some researchers have suggested a more parsimonious approach of using three degrees of freedom for unmeasured confounders[3].

Results

Based on the definition used, there is a wide variation in the number of heat waves across cities (Table 1). In addition, the average duration (in days) of heat waves also varies across cities. For instance, with the cut-off as 97th percentile, Ahmedabad recorded a total of 8 heat waves between 2005 and 2011 (average 1.14 waves per year). This number dropped to six and three respectively when cut-offs of 98th percentile and 99th percentiles were adopted. Shimla recorded the highest number of heat waves (12) from 2005 to 2012 as well as highest average duration (4.3 days) when 97th percentile criterion was used. The least number of heatwaves were recorded for Hyderabad across the definitions used. When the IMD definition was adopted, Ahmedabad had the maximum number of heat waves per year (7.9) whereas Bangalore had the least (2.3).

In the case of cold waves, the same heterogeneity with respect to number of cold waves, their average duration for different definitions was observed across cities (Table 2). For the study period, no cold waves were observed for Bangalore and Hyderabad. For the most severe cold wave definition (1st percentile) the largest number of waves was observed for both Shimla and Mumbai (three waves). However, the average duration of each wave was higher for Mumbai.

Figure 2 shows the additional risk of death based on different heat wave definitions across cities. We observe that across cities, the ‘additional impact’ associated with heat waves was not significant. The clear consistent finding is that as the intensity of heat wave increases (97th to 99th percentile), the associated risk of mortality associated increases. In the most severe heatwaves (99th percentile) the highest risk of mortality was observed for Shimla (1.31, 95% CI: 1.09, 1.53), followed by Hyderabad (1.19, 95% CI: 0.9, 1.48). Bangalore which has temperate climate showed the lowest mortality risk with heat wave (1.04, 95% CI: 0.92, 1.16). Based on the IMD definition, the highest risk was observed for Mumbai (1.10, 95% CI: 1.02, 1.18).

Figure 4 shows that 'additional impacts' associated with cold waves were not significant for the period of study. According to the definition used in this study, no cold waves were observed for Bangalore or Hyderabad. For Ahmedabad, the additional risk of death due to cold waves increased only when there were two or more consecutive days below the 2nd and 1st percentile of minimum temperature. The additional risk of morality for an extreme cold wave (<1st percentile) was 1.16 (95% CI: 0.92, 1.39) for Ahmedabad. An increased mortality risk of 1% was observed for Mumbai only in extreme cold waves. Mumbai is located on the coast and therefore its climate is moderated by land and sea breeze. For Shimla, a decrease in relative risk of mortality with extreme cold wave (risk 0.74, 95% CI: 0.09, 1.39) was noted. This implies that extremes of cold may have a protective effect for Shimla. Although the reasons for this have not been systematically studied, it is possible that extreme cold may modify behaviour and reduce overall exposure as people spend more time indoors.

Discussion

Temperature extremes such as heat waves and cold spells have been studied to a lesser extent in India. Though previous studies have looked at individual heat wave events for India[13,22], they have never linked these extremes of temperature to health outcomes in terms of excess morbidity or mortality. In the current study the modelling choice allows for a separation of heat and cold waves from the effects of high and low temperatures; thus capturing the additional risk of heat or cold waves in addition to that of high temperatures[2,3,19].

As there are no universally accepted definitions of heat and cold waves, this study adopted a variety of definitions based on previous literature and that given by the Indian meteorological department. The additional effects of heat waves (over and above days of high temperature) were found to generally be higher for colder cities like Shimla. Conversely, the effects of cold spells were found to be higher for hotter cities such as Ahmedabad. These findings may be a reflection of population acclimatization – populations in hotter environs are more vulnerable to extremes of cold and vice-versa.

Mortality was found to increase with increases in the intensity of heat waves across all cities. These findings are consistent with other studies that have observed the impacts of heat waves in United States[1] and South Korea[23]. This study used a simple indicator variable to capture heat and cold wave duration. Other studies have further attempted to decompose the heat wave based on intensity, timing in season as well as duration[1,2]. Such a decomposition is especially well suited if heat or wave effects are to be combined across a number of cities to arrive at an average impact across cities or communities. In our study, given the limited number of years for which data was available, the absolute number of heat waves and cold spells were small and thus such decomposition was not always possible.

For Shimla, extreme cold waves may have a protective effect as they are associated with a reduction in relative risk of mortality. Similar reductions in mortality risk associated with extreme cold spells were observed for a study of 99 cities in the United States[2]. This may be explained by physiological processes of acclimatization, as well as behavioural changes in terms of clothing used, housing materials and structures across cities determine the effects of temperature relative to the ‘acclimatization’ level for a given community[24]. Furthermore, in extreme cold weather people may avoid travel and stay indoors, thereby reducing cold exposure[2]. However, further studies are needed to better understand these findings.

It is well understood that mortality is an outcome not only of exposure to temperature extremes but also a function of inherent vulnerability such as age, pre-existing disease, poverty, low education levels, air conditioning or heating access[20,25]. The differences in these factors across cities may also help explain the heterogeneity of mortality across cities. However, our study was not designed to measure the influence due to these variables. For most cities, information on age or cause of death was not available as a result all-cause mortality was assessed as done previously [26]. The underlying assumption is that a short term variation in temperature is unlikely to be correlated with other causes of death (e.g. accidents). Therefore variations of mortality on extreme hot or cold days will most likely be linked to temperature. This underscores the need for adopting better data collection methods on age and cause of death.

In conclusion, this is the first study that examines mortality risks associated with temperature extremes across multiple settings in urban India. Our findings suggest that impacts of temperature on mortality vary across cities and populations. Therefore, planning interventions at a local level should take into account these differences. Whereas an early heat-health warning system has been instituted for the city of Ahmedabad, there is a need to expand this to other cities. Furthermore, warning systems against extremes of cold are also needed to reduce vulnerability. Urban planners and communities should play a pro-active role in adapting to current and future temperature related mortality and morbidity. Cities in colder areas need to be better prepared for heat related morbidity and mortality while the converse is true for cities in hotter climates.

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Figure Legends

Figure 1 shows the additional risk of mortality due to sustained high temperatures across five urban areas in India

Figure 2 shows the additional risk of mortality due to sustained low temperatures for Ahmedabad, Mumbai and Shimla

Table 1 - Heat wave characteristics for different cities

	Ahmedabad (2005 – 11)	Bangalore (2008 – 10)	Hyderabad (2008 – 09)	Mumbai (2005 -12)	Shimla (2005-12)
97th Percentile (°C)	43.2	35.4	41.9	37	29.3
Total no. of waves	8	3	2	10	12
Waves/year	1.14	1	1	1.25	1.5
Avg. days/ wave	3	3.3	2.5	2.3	2.8
98th Percentile (°C)	43.5	35.9	42.6	37.7	29.8
Total no. of waves	6	2	2	8	6
Waves/year	0.86	0.66	1	1	0.75
Avg. days/ wave	3	2.5	2.5	2.1	3
99th Percentile (°C)	44.2	36.2	42.8	38.2	30.4
Total no. of waves	3	1	1	4	5
Waves/year	0.42	0.33	0.5	0.5	0.63
Avg. days/ wave	2	3	2	2	2.2
IMD* definition					
Temperature (°C)	43	36.2	41.7	37.9	29.9
Total no. of waves	55	7	15	22	43
Waves/year	7.9	2.3	7.5	2.8	5.4

*IMD – Indian Meteorological Department

Table 2 - Cold wave characteristics for different cities

	Ahmedabad (2005 – 11)	Bangalore (2008 – 10)	Hyderabad (2008 – 09)	Mumbai (2005 -12)	Shimla (2005-12)
1st Percentile (°C)	7.6	11.2	11.6	11	-2
Number of waves	1	None	None	3	3
Avg. days/ wave	2	NA	NA	2.3	2
2nd Percentile (°C)	8.3	11.5	12.2	12.2	-1.2
Number of waves	5	None	None	5	7
Avg. days/ wave	2.4	NA	NA	2.8	2.6
3rd Percentile (°C)	8.9	11.9	12.7	12.7	-0.2
Number of waves	6	None	None	7	10
Avg. days/ wave	3	NA	NA	3.1	2.5

*No cold waves observed for Bangalore and Hyderabad during the study period