Effect of ambient heat on all-cause mortality in the coastal city of Surat, India

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A wealth of information is available on extreme heat and humidity associated with mortality for cities of the developed world, but there is a dearth in the literature for coastal cities of the developing world. The aim of the present study was to assess the effect of ambient heat on all-cause mortality on the urban population of Surat, a coastal city in India. Retrospective analysis of all cause mortality data with temperature and humidity was performed for the summer months (March–May) for the period 2001–12. Student's *t*-test and correlation coefficient were used to study the relationship between ambient heat and mortality. A total of 36,167 deaths for 961 summer days (2001–12) were analysed. Mean daily mortality was estimated at 37.6 ± 9.4 for the study period. There is an increase of 11% mortality when the temperature crosses 40°C. However, there is an increase of 3 (9%) deaths per day during danger-level heat-risk days and 6 (18%) deaths per day during high-risk heat days (extreme danger) respectively. Mortality seems to be well correlated with the high temperature ($P < 0.001$) and high heat index (HI) values ($P < 0.001$). The effect of extreme heat on mortality is at a peak on day-2 of the maximum temperature. The study concludes that the impact of ambient heat in the increase of all cause mortality is clearly evident and HI is more important than maximum temperature (18% deaths/day versus 11% deaths/day). Therefore, emphasis should be given to develop measures of adaptation towards ambient heat. This analysis may fulfil the needs of policy makers and apply strategies like integrated coastal zone management. Extreme heat-related mortality merits further analysis in order to reduce harmful health effects among Surat's most vulnerable urban population.

Keywords: Ambient heat, mortality, temperature, humidity, urban population.

CLIMATE extremes can have critical general well-being and public health effects[1]. Many studies have revealed that temperature extremes are a major underlying weather-related cause of mortality on both sides of Atlantic ocean[2–7]. Cities experience higher levels of heat exposure than surrounding suburb and rural areas because of the urban heat island (UHI) effect, whereby temperatures in the urban regions are generally 3.5–12°C higher than those outside city limits[8]. The UHI is an artefact of the complex built environment, the lack of cooling vegetation and the high density of human activities in urban areas and is a result of differences in the energy balance of urban and rural environments. Various possible approaches for mitigation of UHI effects are white roofs, green roofs and planting trees in cities. New York City installed and monitored green roofs on a few building as a mitigation effort[9]. Germany is using eco-proof technology/urban vegetation. Many German cities possess by-laws which ensure that industrial building incorporates a green roof. A combination of vegetation and albedo enhancement helped reduce heat-related mortality by 40–99% across the three metropolitan regions of Atlanta, Philadelphia and Phoenix in the US[10]. This demonstrates that climate adaptation strategies can be designed to lessen the risk of heat exposure through mitigation of the UHI effect. However, the heat management strategies that are effective in reducing the mortality vary with region[10].

Throughout the world, a changing climate has increased the risk of temperature-related morbidity and mortality, as is evident from studies in Australia, Greece, Russia and the US[11–18]. The mortality impact of extreme heat has been explored for many regions of the world[19–21]. The US and European data suggest that the contribution of mortality due to heat waves is much higher than mortality due to any other extreme weather events[22,23]. India also witnessed a series of heat waves with considerable mortality[24], for instance, heat wave-related deaths were highest for Rajasthan, Bihar and Uttar Pradesh during the period 1978 and 1999 (ref. 25). In 1998 Odisha faced an exceptional heat wave situation which caused the death of 2042 people[26]. A similar situation was also noted from Andhra Pradesh in 2003, which killed 1421 people[27]. Azhar *et al.*[28] reported excess 1344 all-cause mortality associated with the May 2010 heat wave for Ahmedabad city in Gujarat[28]. This shows that significant increase in premature heat-related mortality poses a threat to public health in many Indian states. Nonetheless, a discussion of

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the mortality and health effects of extreme heat is missing from India's National Action Plan on Climate Change (NAPCC)[29].

India Meteorological Department (IMD) has defined heat wave as when either there is an excess of 5°C over a normal daily historical maximum temperature (30 year average) of less than 40°C; or an excess of 4°C over a normal historical maximum temperature of more than 40°C. However, the heat wave is acknowledged when the actual maximum temperature is above 45°C without considering the normal historical maximum temperature[28–30]. But the criteria to determine heat-related deaths are not widely accepted and thus the true magnitude of heat-related mortality may be unknown[31,32]. More so, there are relatively scant data available for India, especially coastal cities, as extreme heat has not been recognized as a significant public health problem for these cities. The atmospheric flow around a coastal city is complicated by UHI effects and sea breeze which in turn influence air pollution and human health[33]. Coupled with this, coastal cities behave differently from a climate change perspective[34,35] and Surat is one of them. Socio-economic impacts of the extreme weather events (heat waves, floods) may impose a wide array of stressors on urban areas, especially slums, because of massive growth of population and migration (55% of Surat's population is migrants)[36] towards Surat city. Migrant labourers from other parts of Gujarat, Maharashtra and eastern India, have settled down mainly along the major transportation corridors, river and creek banks, and in the vicinity of industrial areas in Surat. This has led to the formation of informal settlements characterized by high population density and associated public health risks. These densely populated areas are similar to slums, with no or substandard basic facilities like drinking water, roads, light, sanitation, etc. and are highly prone to disaster. The working conditions of slum-dwellers frequently require them to stay outdoors for prolonged time periods, thereby exposing them to temperature extremes. Hence the migrant population is more vulnerable in general[37,38].

Apart from huge incoming migrants, population growth and pressure on resources have forced the city limits to expand rapidly from 8.18 to 326.515 sq. km. Although there is no universally accepted definition, heat and cold waves are understood to be extended periods of extreme temperature[39]. In Surat, relative humidity is high in the air throughout the year; so only temperature values will not provide the perfect scenario of how hot it feels in summer. Coupled with this, the combination of high temperature and high humidity may cause an extreme weather event for a coastal city like Surat. However, the IMD definition for heat waves does not consider humidity. According to World Bank Sustainable Development Network[40], Surat is also one of the world's most climate change-affected cities, as there is a history of floods every 4 years and maximum summer temperature increased to 1.6°C from 2011 to 2014. There were 37 heat-wave days with maximum temperature ≥40°C from 2010 to 2014 (summer days). However, studies assessing the mortality risks of temperature extremes in Surat city are largely absent.

This article reports the association of daily maximum temperature, relative humidity and heat index (HI) on all-cause mortality for summer (March–May) from 2001 to 2012 for the urban population of Surat city.

Materials and method

Study area

Surat is India's ninth most populated city having a population of 4.5 million with 82.91% literacy rate and lies between 21°10′N lat. and 72°50′E long[41]. It is the commercial capital of Gujarat and rests on the bank of the Tapi River, which flows into the Arabian Sea[42]. The city has a diverse demographic profile and has witnessed exponential urbanization rates over the past several decades. According to the report on Surat City Resilience Strategy[43], from its current 4.5 million population, Surat is projected to grow to around 6.4 million by 2021 and 8.5 million by 2031.

The seasons of Surat city are broadly divided into summer, winter and monsoon, with fluctuations in temperature. Due to proximity to the sea, it is predominately humid and hot and represents the tropical savanna climate. Summer months are hot with mean humidity around 60% and temperatures ranging from 37.78°C to 44.44°C.

Study design

Retrospective analysis of all-cause mortality data with temperature and humidity was done as part of a collaboration with Surat Municipal Corporation (SMC) to develop strategies for climate change adaptation for Surat.

Definitions

Relative humidity: This is defined as the ratio of the partial pressure of water vapour (H_2O) in the mixture to the saturated vapour pressure of water at a given temperature.

Heat index: HI (apparent temperature) is a measure of how hot it really feels when relative humidity is factored with the actual air temperature.

Apart from the Rothfusz equation[44], the wet-bulb globe temperature (WBGT) index[45], discomfort index[45] and environmental stress index (ESI)[46] were considered for measuring the heat stress, as these are in use since more than four decades. However, WBGT has inherent limitation of its applicability across a broad range of potential scenarios and environments because of cumbersome and impractical measuring of T_g (black globe temperature) and use of discomfort index is inappropriate where there are significant thermal radiations. ESI is appropriate for Surat climate, but it is composed of ambient temperature, relative humidity and solar radiation. Data on solar radiation are not available. Hence, based on the availability of information only on temperature and humidity, the Rothfusz equation for HI is more appropriate for the present analysis.

The Rothfusz equation for HI is used as it is applicable only when air temperature and humidity are higher than 26°C and 39% respectively. More so, this equation is also widely used for similar settings like Surat[47,48].

Heat index equation:

$$\begin{aligned} \text{HI} = & -42.379 + 2.04901523T + 10.14333127R \\ & - 0.22475541TR - 6.83783 \times 10^{-3} T^2 \\ & - 5.481717 \times 10^{-2} R^2 + 1.22874 \times 10^{-3} T^2 R \\ & + 8.5282 \times 10^{-4} TR^2 - 1.99 \times 10^{-6} T^2 R^2, \end{aligned}$$

where T is the ambient dry bulb temperature (°C), and R the relative humidity (%).

The HI value per day was computed from per day maximum temperature and mean humidity data. The various categories of HI have been summarized as follows[49]: extreme danger – >130°F or >54°C; danger – 105–130°F or 41–54°C; extreme caution – 90–105°F or 32–41°C, and caution – 80–90°F or 27–32°C.

Heat wave: A heat wave is a prolonged period of excessive heat most often under humid conditions and may cause heat stroke or even death in summer[49]. In this analysis, a hot day or heat wave is taken as maximum temperature above 40°C.

Data collection and analysis

The data on temperature and humidity were collected online from Tutiempo Network, S.L[50] for the summer months of 2001–12. The values were collected for daily mean, maximum and minimum temperature (°C) and daily mean humidity (%) for Surat city. The mortality data of the city were obtained from the Birth and Death Registration Department of SMC for the period from 2001 to 2012. Before data analysis, non-resident Surat city deaths were excluded from the data set through sorting the place of residence (town/village).

Data were processed in Microsoft Excel and analysed using SPPS version (16.0). Descriptive and bivariate analysis was conducted. Quantitative variables were summarized using mean and standard deviation. Student's *t*-test was used for testing the significance of differences between the mean death values at maximum temperature of <40°C and ≥40°C and caution heat-risk days versus danger and extreme danger heat-risk days. Pearson's correlation coefficient was used to study the relationship between ambient heat and mortality. Significance was set at $P < 0.05$. We also used unconstrained distributed lag model to identify the extent to which heat-related excesses were followed by deficits (mortality displacement).

Days with missing data for temperature and/or humidity were excluded from the analysis.

Results

A total of 36,167 deaths for 961 summer days (2001–2012) were analysed with relation to temperature and relative humidity.

Table 1 shows that the yearly mean maximum temperature during summer ranges from 34.64 ± 2.50°C in 2008 to 36.67 ± 3.16°C in 2010. Highest recorded value of relative humidity (80–81%) is almost similar across the study period. The yearly mean HI is lowest in 2008 (45.61 ± 4.88°C) and highest in 2010 (52.75 ± 7.61°C). The year 2010 was warmer in terms of high temperature with the maximum temperature of ≥40°C for 22 days compared to rest of the study period (as shown in Table 1).

Table 2 shows that the mean daily all-cause mortality has been estimated at 37.6 ± 9.4 for the study period. The minimum and maximum mean daily mortality is 26.62 ± 5.52 and 46.38 ± 8.03 for 2002 and 2010 respectively.

The mean number of deaths per day at daily maximum temperature of less than 35°C is 36.7, which increased to 41.7 at daily maximum temperature of 40°C and above. This shows that four (11%) deaths per day increases at the temperature of 40°C and above. There is an inverse relationship between mean mortality and relative humidity, but there is a direct relationship between mortality and HI. The mean number of deaths per day for less risky or caution days (HI = 27–31°C) is 34, which increases to 37 at HI of 41–54°C (danger days), and 40 at HI of above 54°C (extreme danger/most risky days). This shows that 3 (9%) deaths per day increases during danger days and 6 (18%) deaths per day increases during extreme danger days (Table 3).

Table 4 indicates that the mean daily mortality shows a significant association with daily maximum temperature ($P < 0.001$) and HI or discomfort index from caution to danger risk days ($P < 0.001$). Pearson's correlation coefficient for 2010 shows increase in all-cause mortality with a lag of two days ($r = 0.443$), but after two days it becomes weak. This shows that the lag effect of extreme heat on mortality is at a peak on day-2 of

Table 1. Year-wise statistics of mean maximum temperature, humidity, heat index (HI) and days with maximum temperature ≥40°C

Year	Maximum temperature (°C) mean ± SD	Highest recorded value of temperature (°C)	Relative humidity (%) mean ± SD	Highest recorded value of relative humidity (%)	HI (°C) mean ± SD	Highest recorded value of HI (°C)	Maximum temperature ≥40°C (days)
2001	35.00 ± 2.60	40.7	62.74 ± 13.36	89	47.46 ± 6.16	70	10
2002	35.53 ± 3.18	44.4	60.76 ± 14.75	84	48.40 ± 8.59	94	9
2003	35.95 ± 2.64	43.2	61.38 ± 12.60	81	49.95 ± 7.67	85	7
2004	35.55 ± 2.57	41.4	59.84 ± 15.45	82	49.34 ± 6.32	64	15
2005	34.92 ± 2.48	41.2	57.27 ± 15.95	83	47.29 ± 7.03	65	9
2006	34.70 ± 2.39	40.8	61.71 ± 13.20	80	46.03 ± 6.59	72	4
2007	35.64 ± 2.63	42.0	65.07 ± 12.75	79	50.86 ± 5.44	66	9
2008	34.64 ± 2.50	41.0	63.61 ± 13.39	82	45.61 ± 4.88	60	3
2009	35.79 ± 2.44	42.2	57.17 ± 15.47	79	48.01 ± 5.14	65	13
2010	36.67 ± 3.16	42.9	61.73 ± 14.09	80	52.75 ± 7.61	75	22
2011	35.23 ± 2.01	39.0	62.62 ± 13.20	79	48.64 ± 5.65	64	2
2012	35.38 ± 2.62	40.6	61.87 ± 12.97	80	48.40 ± 6.75	62	2

Table 2. Year-wise highest recorded temperature, deaths and summer days

Year	Maximum temperature (°C)	Total deaths	No. of days (summer)*	Mean deaths per day
2001	40.7	2437	85	28.67 ± 6.03
2002	44.4	2076	78	26.62 ± 5.52
2003	43.2	2619	85	30.81 ± 6.88
2004	41.4	2583	77	33.55 ± 6.23
2005	41.2	2546	73	34.88 ± 5.72
2006	40.8	3221	87	37.02 ± 6.27
2007	42.0	2177	56	38.88 ± 7.17
2008	41.0	3689	90	40.99 ± 7.35
2009	42.2	3161	77	41.05 ± 6.44
2010	42.9	3896	84	46.38 ± 8.03
2011	39.0	3822	83	46.05 ± 7.16
2012	40.6	3940	86	45.81 ± 7.09
	Total	36,167	961	37.63 ± 9.40

*Data on temperature were missing for 44 days and data on humidity were missing for 99 days. Hence these days were excluded from the analysis because Rothfusz equation for HI is applicable only when air temperature and humidity are higher than 26°C and 39% respectively.

Table 3. Mortality with temperature and humidity

Factor	No. of deaths	No. of days	Mean no. of deaths per day
Maximum temperature (°C)			
< 35	17,527	478	36.7
35–40	15,721	413	38.1
40–45	2919	70	41.7
Relative humidity (%)			
40–49	5130	130	39.4
50–59	7880	203	38.8
60–69	7532	206	36.5
70–79	14,926	403	37.0
80–90	699	19	36.7
Heat index (category in °C)			
Caution (27–31)	68	2	34.0
Extreme caution (32–40)	3427	96	35.6
Danger (41–54)	25,098	674	37.2
Extreme danger (>54)	7574	189	40.1
Total	36,167	961	

Table 4. Association of maximum temperature and HI with summer mortality

Factor	Total deaths	Mean deaths	*t*-test	*P*-value
Maximum temperature (°C)				
<40	33,192	39.6 ± 9.2	24.89	<0.001
≥40	2,975	44.2 ± 9.7		
HI (type of day)				
Caution days (27–40°C)	3,495	37.7920	15.64	<0.001
Danger days (>41°C)	32,672	40.2171		

Table 5. Lag time correlation between temperature and humidity with all-cause mortality counts, 2010

Pearson correlation coefficient	No lag	One day lag	Two days lag	Three days lag	Four days lag
Maximum temperature (°C)	0.282*	0.351*	0.443**	0.261*	0.173*
Minimum temperature (°C)	0.137***	0.125***	0.102***	0.131***	0.113***
Humidity (%)	–0.094*	–0.258*	–0.296*	–0.093*	–0.002*

*$P < 0.05$; **$P < 0.01$; ***Non-significant.

the maximum temperature, but decreases thereafter (Table 5).

Discussion

High temperature, especially along with humidity is a matter of concern in the context of Surat climatology as with most other coastal cities. We studied the association of mortality with maximum temperature and humidity and found that both temperature and heat index are important factors affecting all-cause mortality for Surat city. Although similar heat-mortality studies have been conducted in American, Chinese and European cities, to the best of our knowledge, there have been no studies on the urban population of Surat city (one of the 20 most climate change-affected cities in the world)[51].

There is significant increase in mortality risk in the population with increase in maximum temperature, that confirms previous results obtained in other places[52–54]. Heat and moisture content play a significant role in elevated heat index factor, which can lead to discomfort and health threat for the urban population of Surat city. The high heat index values seem to be well correlated with the all-cause mortality, characterized by the combination of very high temperatures (>36°C) and relative humidity (60–70%) and consistent with the study by Monteiro *et al.*[35]. HI is more important than maximum temperature as evident from our analysis by increase of 18% deaths/day versus 11% deaths/day. Hence, there is a need for the inclusion of humidity measures while calculating health/mortality impacts of heat waves.

The present analysis reveals that humidity is almost higher than 60% throughout the study period and temperature above 40°C (HI is more than 54ºC) for 105 out of 961 summer days. This is known as extreme danger/high-risk period and is critical for increased mortality due to extreme heat events. Apart from excess mortality, it can also affect (a) work performance of the population that in turn may have an impact on the economy of Surat (city with high industrial production), and (b) health and may lead to dangerous heat disorders like muscles cramps. Hence, Surat needs to plan and implement interventions to such adverse climatic heat affects.

Some limitations of the present analysis need to be acknowledged.

(1) The mortality data are from Birth and Death Registration Department of SMC, which relies on sentinel centre and Integrated Disease Surveillance Project (IDSP) data (the disease surveillance system in India). In some sentinel units, few causes of death, though not the deaths themselves, may not be accurately reported if these are considered sensitive and deaths among the homeless are unlikely to have been registered, potentially resulting in an underestimation of the mortality risk. However, we argue that these concerns will not affect our findings, as the number of the such sensitive deaths and deaths among the homeless may be small.

(2) The present analysis is based on the secondary data which are less likely meant for research purpose. Hence, we were not able to stratify the deaths by socio-demographics status. However, we believe that data disaggregated on socio-demographic variables would have provided useful insights on vulnerability.

(3) Due to unavailability of data on age or cause of death, all-cause mortality was assessed as done previously[28,55]. We believe that a short-term variation in temperature is less likely to be correlated with other causes of death like accidents.

(4) We were not able to conduct a cause-specific analysis and isolate the heat-related deaths because of lack of data on cause-specific deaths. Hence, the outcome is all-cause mortality, and our estimate may be an overestimate or underestimate of the true effect of the heat and humidity on mortality.

(5) Correlation analysis was conducted only for the year 2010 (warmest year for Surat during entire study period).

Conclusions

A total of 36,167 deaths for 961 summer days (2001–2012) were analysed. Mean daily all-cause mortality was estimated at 37.6 ± 9.4 for the study period. There is an increase of 11% all-cause mortality when temperature crossed 40°C. There is a direct relationship between mortality and HI. There is an increase of 3 (9%) deaths per day during danger days and 6 (18%) deaths per day during extreme danger days respectively.

Mean daily mortality shows a significant association with daily maximum temperature and HI. The effect of extreme heat on mortality is at a peak on day-2 of the maximum temperature. Given the trends associated with climate change, dangerous periods of extreme heat are likely to occur more frequently, suggesting the need for measures to reduce population vulnerability. Our analysis may fulfil the needs of policy makers and apply strategies like integrated coastal zone management. Extreme heat-related mortality merits further analysis in order to reduce harmful health effects among Surat's most vulnerable population.

Recommendations

(1) We suggest that IMD definitions may be re-looked and tweaked, especially for coastal cities in view of high humidity, and recent climate change. Humidity values should be considered while calculating mortality due to heat waves.

(2) We also recommend that short- and medium-range temperature forecasts and observed population health effects could be used to generate early warnings of extreme heat which might condense the number of heat-related mortalities. Early warning systems also needed for Surat specific heat and health action plan and response capacity for health professionals and staff of Surat Municipal Corporation.

(3) Further evaluation of a lagged effect of extreme heat on mortality through time-series analysis is required.

(4) Mobile applications need to be designed for creating public awareness through messages (SMS) about the harmful effects of the extreme heat.

(5) Public–private partnership and inter-convergence between all stakeholders need to be developed and nurtured to facilitate interdisciplinary work and effective implementation of the required interventions as evident by this collaboration with SMC.

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