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ORIGINAL PAPER

Indian summer heat wave of 2015: a biometeorological analysis using half hourly automatic weather station data with special reference to Andhra Pradesh

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Abstract Heat wave is a hazardous weather-related extreme event that affects living beings. The 2015 summer heat wave affected many regions in India and caused the death of 2248 people across the country. An attempt has been made to quantify the intensity and duration of heat wave that resulted in high mortality across the country. Half hourly Physiologically Equivalent Temperature (PET), based on a complete heat budget of human body, was estimated using automatic weather station (AWS) data of four locations in Andhra Pradesh state, where the maximum number of deaths was reported. The heat wave characterization using PET revealed that extreme heat load conditions (PET >41) existed in all the four locations throughout May during 2012–2015, with varying intensity. The intensity and duration of heat waves characterized by "area under the curve" method showed good results for Srikakulam and Undi locations. Variations in PET during each half an hour were estimated. Such studies will help in fixing thresholds for defining heat waves, designing early warning systems, etc.

Keywords Heat wave · PET · AWS · Intensity · Duration · Death rate

Introduction

The frequency, intensity, and duration of extreme weather events have been on the rise for the past few decades. Heat wave is a threatening weather-related extreme event, which has an impact on economy, ecology, and society (Keggenhoff et al. 2015). The frequency of heat waves has increased in large parts of Europe, Asia, and Australia (IPCC 2014). Although there is no universally accepted definition, they are understood to be periods of unusually hot and dry or hot and humid weather that have a subtle onset and cessation, a duration of at least 2–3 days, usually with a discernible impact on human and natural systems (McGregor et al. 2015). Since there is no absolute universal value, such as a given temperature that defines what is extreme heat, heat waves are relative to a location's climate: The same meteorological conditions can constitute a heat wave in one place but not in another (McGregor et al. 2015). Plenty of literature is available relating heat stress generated due to heat wave with mortality rates (Gosling et al. 2008; Trigo et al. 2005; Isaksen et al. 2016; Schaeffer et al. 2016). India has witnessed increased incidence of heat waves in the recent past. The number of deaths reported due to heat stroke across the India during 2000–2015 is presented in Fig. 1.

It is clear from Fig. 1 that there is a rise in the deaths reported after 2008 and 2015 heat wave tops the chart. Despite these alarming death rates, the country has made very little progress in creating awareness among the public and developing forewarning systems. This figure shows that there is an urgency to undertake a scientific study to understand the intensity and duration of heat waves in India and its effect in causing human mortality.

A warming trend of 0.8–1°C per century has been observed over India (Kothawale et al. 2012). In recent years, heat wave casualties have increased. Abnormally high temperatures were observed during April–June during 2010 to 2015 across the country. Heat wave also caused death of wildlife, birds, and poultry in different states of India (NDMA 2016).

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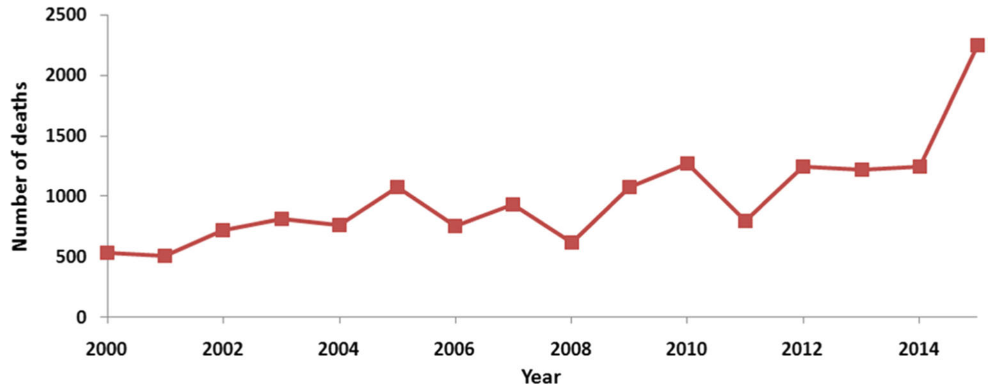

Fig. 1 Deaths reported due to heat stroke in India during 2000–2015 (NCRB 2015; NIDM 2015)

Most of the heat-related deaths can be prevented by early warning systems and heat wave action plans. Scientific understanding of the impact of heat waves on death rate is necessary to design a heat wave action plan. Impact of heat wave at different time of a day may cause different physiological effects to body.

Various attempts have been made by the researchers all over the world to characterize the heat waves. In India, India Meteorological Department (IMD) has defined heat wave as (as given in IMD website, www.imd.gov.in):

When maximum temperature (Tmax) of a station reaches ≥40°C for plains and ≥30°C for hilly regions

1. Based on departure from normal
   a. Departure of Tmax from normal is 4.5–6.4°C: heat wave
   b. Departure of Tmax from normal is ≥6.5°C: severe heat wave
2. Based on actual maximum temperature
   a. When actual Tmax ≥45°C: heat wave
   b. When actual Tmax ≥47°C: severe heat wave
3. Criteria for heat wave for coastal stations
   a. When departure of actual Tmax from normal is greater than 4.5°C. Heat wave may be described provided actual Tmax ≥37°C

IMD criteria only consider the temperature during heat waves. Moreover, the definition is based on daily basis, which does not consider the cumulative impact of heat stress in a region. In order to develop a forewarning system, the criteria should consider other weather elements like wind speed, relative humidity, and solar radiation, which will influence intensity, duration, and spatial extent of heat waves. Moreover, to relate heat wave conditions to death rate, there is an exigency to understand the changes in human physiology during the heat waves. The recent heat wave, which struck a major swath of the country during second fortnight of May 2015, has killed 2248 people out of which 1677 are from a single state, Andhra Pradesh (NIDM 2015). The uniqueness of 2015 heat wave was that it started early in the day and continued for 6 to 8 hours continuously for 8 to 10 days. This influenced the human physiological activities, causing dehydration and death. To understand the variation of thermal stress variation within a day and during the heat wave period and to check its link to reported death rate, a multilocation study was carried out on the thermal comfort of the human body and its variability in the state of Andhra Pradesh, India. This study aims to utilize half hourly automatic weather station (AWS) data to estimate a human thermal comfort index, to estimate the intensity and duration of heat waves and its relation to daily reported death rate.

Data and methods

All India Coordinated Research Project on Agrometeorology (AICRPAM) under National Innovations in Climate Resilient Agriculture (NICRA) project has established a network of 100 AWS in most climate change vulnerable locations of India. These AWS are providing real-time weather data on half an hour interval. As the impact of recent heat wave (in May 2015) had caused maximum number of deaths in the state of Andhra Pradesh, we have selected five locations AWS data for this study. The location names are Pedavegi, Anantapur, Kurnool, Undi, and Srikakulam. Weather data viz., maximum and minimum temperatures, relative humidity, wind speed, and solar radiation of May month, has been collected on a half hourly interval basis for the years 2012 to 2015 and put to quality check. It was found that temperature data of Pedavegi was beyond acceptable limits. Hence, the study was performed in four locations namely, Anantapur, Kurnool, Undi (West Godavari), and Srikakulam (Fig. 2). Daily death rates reported in these districts during 15–31 May were collected from Andhra Pradesh State Revenue (Disaster Management) Department.

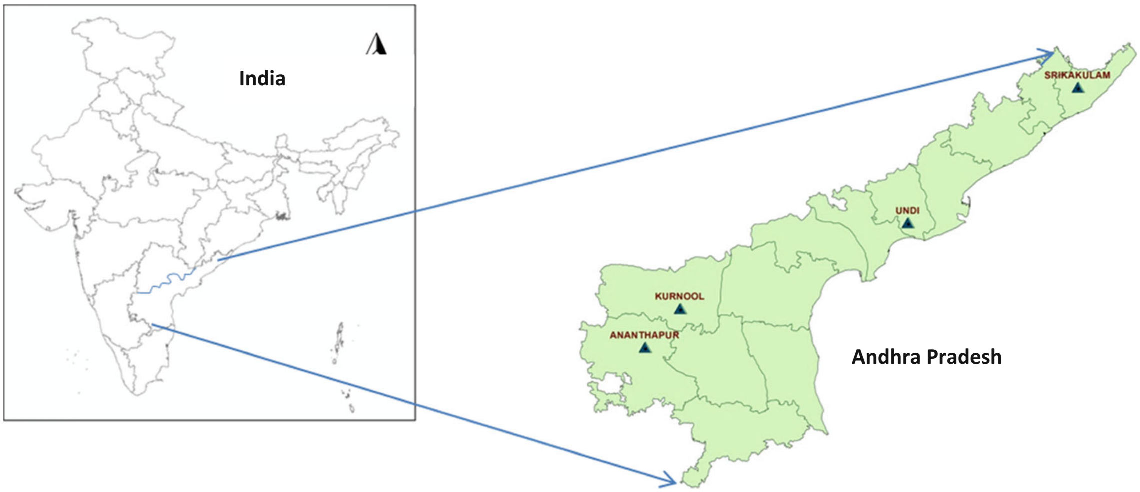

Fig. 2 Study location

Study locations

Anantapur is located at 14.68° N, 77.6° E. It has an average elevation of 335 m. Anantapur has an arid climate, with hot and dry conditions for most of the year. The maximum temperatures range between 29°C (winter) and 41°C (summer), and the minimum temperature ranges between 17°C (winter) and 27°C (summer). The average annual rainfall is about 560 mm. The normal relative humidity at Anantapur during second fortnight of May is 48%.

Kurnool is located at 15.83° N, 78.05° E. It has an average elevation of 273 m. Kurnool also has a semiarid climate with temperatures ranging from 26 to 46°C in the summer and 12 to 31°C in the winter. The average annual rainfall is about 705 mm. The normal relative humidity at Anantapur during second fortnight of May is 46%.

Srikakulam is located at 18.24° N, 83.54° E. It has an average elevation of 36 m. The temperatures range from 27 to 35°C in the summer and 17 to 27°C in the winter. The average annual rainfall is about 1150 mm. It is vulnerable to the depressions and tropical cyclones formed over Bay of Bengal. The normal relative humidity at Anantapur during second fortnight of May is 80%.

Undi is located at 16.35° N, 81.27° E. It falls a hot humid region and about 25 km away from Bay of Bengal. It has an average elevation of 11 m (898 ft). The temperatures range from 27 to 38°C in the summer and 18 to 28°C in the winter. The average annual rainfall is about 1100 mm (28 in). The normal relative humidity at Anantapur during second fortnight of May is 67%.

Various thermal indices have been developed to quantify the heat exchange between human body and thermal environment. For warm conditions, indices usually consist of combinations of dry-bulb temperature and different measures of humidity (McGregor et al. 2015). There are comprehensive reviews which explain such biometeorological indices (Fanger 1970; Parsons 2003; Blazejczyk et al. 2012), which describe the required for estimation and their strength and weaknesses. The major limitation of all these indices is their empirical nature. The cause-effect relationship is not accounted in these types of indices. Process-based heat budget models can overcome this drawback. In these models, heat exchange between human body and the thermal environment is described using energy balance equation. The thermal comfort of an individual is the result of a response to the balance between heat gain and losses (McGregor et al. 2015). The concept of physiologically equivalent temperature (PET) assumes significance in this context. PET is a thermal comfort index based on a complete heat budget of the human body and considers both meteorological and thermo-physiological aspects (Höppe 1999; Matzarakis et al. 1999). The heat balance equation for the human body is (Matzarakis et al. 1999; Hoppe 1993)

$$\mathbf{M}+\mathbf{W}+\mathbf{R}+\mathbf{C}+\mathbf{E_D}+\mathbf{E_{Re}}+\mathbf{E_{SW}}+\mathbf{S}=0$$

where M is the metabolic rate (internal energy production by oxidation of food), W is the physical work output, R is the net radiation of the body, C is the convective heat flow, E_D is the latent heat flow to evaporate water into water vapor diffusing through the skin (imperceptible perspiration), E_{Re} is the sum of heat flows for heating and humidifying the aspirated air, E_{Sw} is the heat flow due to evaporation of sweat, and S is the storage heat flow for heating or cooling the body mass. The individual terms of the equation may be positive in the case of an energy gain (M is always positive) and may be negative—in the case of an energy loss (W, E_D, and E_{SW} are always negative). Watt is considered as the starting unit of all the heat flows. All components required for the assessment of the impact of ambient thermal conditions on human comfort can be calculated using synoptic or climatological data—air temperature, air humidity, wind speed, and short- and long-wave radiation—that are closely related to the thermo-circulatory system of the human body (Matzarakis et al. 1999; VDI 1998).

PET provides the equivalent temperature of an isothermal reference environment with a water-vapor pressure of 12 hPa (50% at 20°C) and light air (0.1 m/s), at which the heat balance of a reference person is maintained with core and skin temperature equal to those under the conditions being assessed. For the reference person, a typical indoor setting is selected with work metabolism of 80 W added to basic metabolism and a heat resistance of clothing of 0.9 clo (1 clo = 0.155 K/m^2/W).

The steps involved in calculation of PET are as follows (Matzarakis and Amelung 2008):

- Calculation of the thermal conditions of the body with MEMI for a given combination of meteorological parameters.
- Insertion of the calculated values for mean skin temperature and core temperature into the model MEMI and solving the energy balance equation system for the air temperature *T*a (with v = 0.1 m/s, VP = 12 hPa, and *T*mrt = *T*a).

The influence of humidity on PET is restricted to latent heat fluxes via respiration and via diffusion through the skin. The PET assessment scale is derived by calculating Fanger's Predicted Mean Vote (PMV) (Fanger 1970) for varying air temperature in the reference environment using the settings for the PET reference person. The range of PET (in °C) and related physiological stress and thermal perception are given in Table 1.

PET was estimated using Rayman version 1.2 software (Matzarakis et al. 2000). The main feature and advantage of RayMan compared to other similar models are the calculation of short- and long-wave radiation fluxes, the possibility to evaluate the thermal environment throughout the year for both cold and hot seasons, and the use of a commonly known unit (°C) (Grigorieva and Matzarakis 2011). The input parameters used were half hourly mean air temperature, relative humidity, and wind velocity, apart from location details (latitude, longitude, and altitude, and time zone).

PET was calculated at half hourly intervals for the four locations during 1–31 May for 2012–2015. Half hourly variations in PET over the mentioned period were analyzed for all 4 years. In order to assess the impact of heat stress on human death rate, we define the threshold value of PET >41 (extreme heat load). To quantify the impact of duration and intensity of heat waves, the area under the curve method was used. Area under the curve of PET >41 was estimated daily (Fig. 3), and this was plotted with reported deaths.

Table 1 PET ranges (°C) and related heat stress and thermal perception (Matzarakis and Mayer 1997)

PET (°C)	Heat stress	Thermal perception
<4	Extreme cold stress	Very cold
4–8	Strong cold stress	Cold
8–13	Moderate cold stress	Cool
13–18	Slight cold stress	Slightly cool
18–23	No thermal stress	Comfortable
23–29	Slight heat load	Slightly warm
29–35	Moderate heat load	Warm
35–41	Strong heat load	Hot
>41	Extreme heat load	Very hot

Results

Characterization of 2015 May heat wave at Andhra Pradesh using PET

PET was computed for the four selected locations in the state of Andhra Pradesh of India. A large variation in PET was observed across the locations. A detailed analysis of intensity and duration of heat waves in half hour interval was presented. The results of the analysis are given in Figs. 4, 5, 6, and 7.

Anantapur

Anantapur has an arid climate. In May 2012, PET analysis showed that extreme heat load conditions prevailed mainly between 11 a.m. and 5 p.m. (Fig. 4). Considerable "comfort" period (PET <23) prevailed during 1–17 May (between 12 a.m. and 6 a.m.). This is important because the heat stress generated in the daytime can be alleviated with this "comfort period." May 2013 PET values indicated very hot first fortnight with PET >41 during 9 a.m.–6 p.m. Barring few hours on May 23 and 24, there was no comfort period up to 27 May. This is an alarming situation, which will amplify the effects of heat stress generated in the daytime. Mid part of 2014 May (15–18th) experienced PET >41 from 8 a.m. to 6 p.m., i.e., severe heat stress conditions of 10 h. First fortnight of 2015 May had PET >35 (i.e., either strong or extreme heat load) during 8 a.m. to 6 p.m. But, what makes the heat wave of 2015 May more dangerous is that hours with PET >41 (extreme heat load) persisted in the same intensity throughout the month, and there were hardly 6 days where comfortable conditions existed.

Kurnool

Out of 4 years, 2014 and 2015 appeared to have faced heat stress with comparatively greater intensity (Fig. 5). May 2015

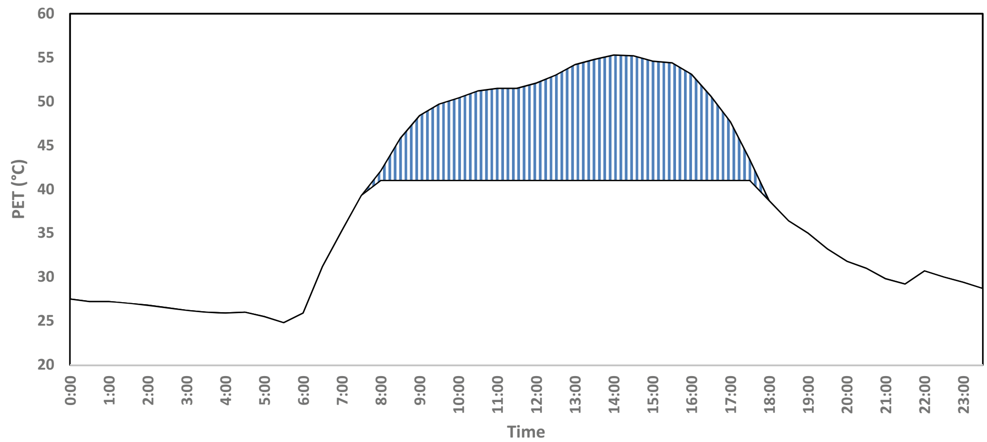

Fig. 3 Area under the curve of extreme heat load (PET >41)

had the least "comfortable" hours compared to others. The second fortnight of May 2015 witnessed PET >35 from 7 a.m. to 6 p.m. (11 h). In the nighttime, also the condition was either warm or slightly warm, which might have not given any relief to alleviate the heat stress caused in the day time.

Srikakulam

From Fig. 6, it appears that second fortnight of May suffered greater heat stress during all years. But, the intensity and duration of stress hours were more in 2014. During 2015, high amount of heat stress prevailed during May 19–31 (extreme heat stress during 8 am to 5 pm). Notably, there were no comfort hours during the same period in 2015.

Undi (west Godavari)

Figure 7 represents the ideal picture of heat wave, especially during 2015. During May 20–28, 2015, there was a sudden rise in heat stress, as evident from Fig. 7. On 25 May, from 7 a.m. to 7 p.m., PET values were more than 35 (strong heat load). Another important observation is that "comfort hours" did not exist in second fortnight of 2015 May, except few hours on 17 May.

Impact of heat waves on human death rate

The intensity, duration, and timing of heat waves can influence the risk of heat-related mortality. In the present study, the intensity and duration of heat waves were quantified by the

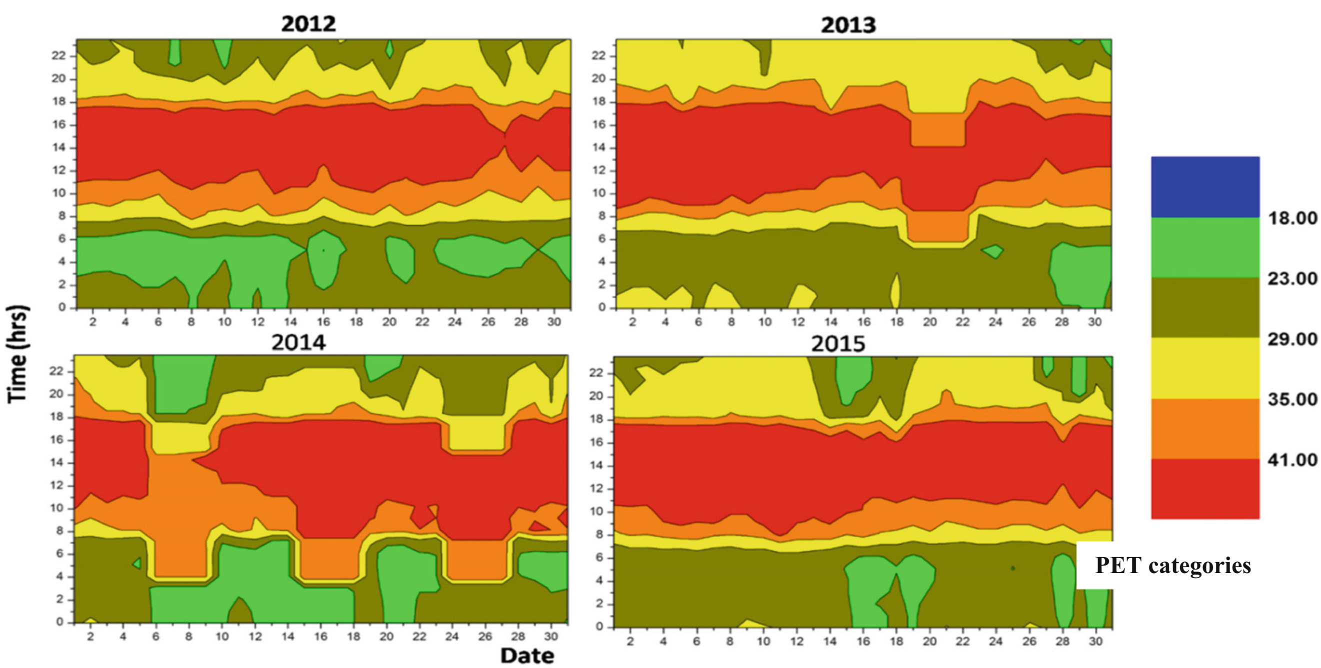

Fig. 4 PET (°C) over Anantapur District of Andhra Pradesh during May

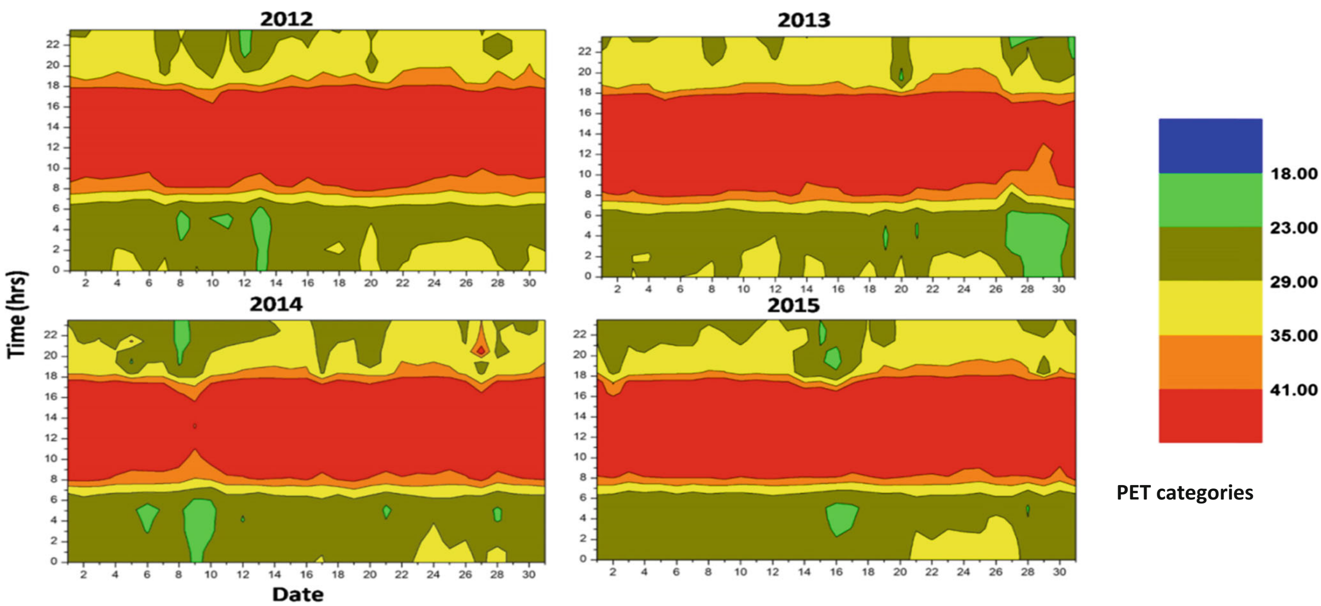

Fig. 5 PET (°C) over Kurnool District of Andhra Pradesh during May

area under the curve method. Area under the curve of PET >41 was estimated for each day in May, and it was correlated with reported death rates (Figs. 8, 9, 10, and 11).

As mentioned earlier, Anantapur has an arid climatology. Maximum deaths were reported on 29 May. Though there is a slight increase in the area under the curve of PET >41 from 27 to 29 May, it is not sufficient to explain the high number of deaths reported (Fig. 8). This indicates that separate threshold values for PET are required for this location. At Karnool, the second fortnight of May showed an increasing trend in the area under the curve of threshold PET, and maximum deaths were reported during 22–28 May (Fig. 9). A clear-cut relation between the number of deaths and area under the curve of PET >41 was missing here also. At Srikakulam, deaths were reported during 19–31 May and area under the curve of PET >41 also increased after 18 May (Fig. 10). May 24 and 26 represented the peak of area under the curve of PET > 41°C, and maximum deaths were also reported during May 24 and 26. This methodology is showing promising results in this location. No time lag was observed between peaks of area

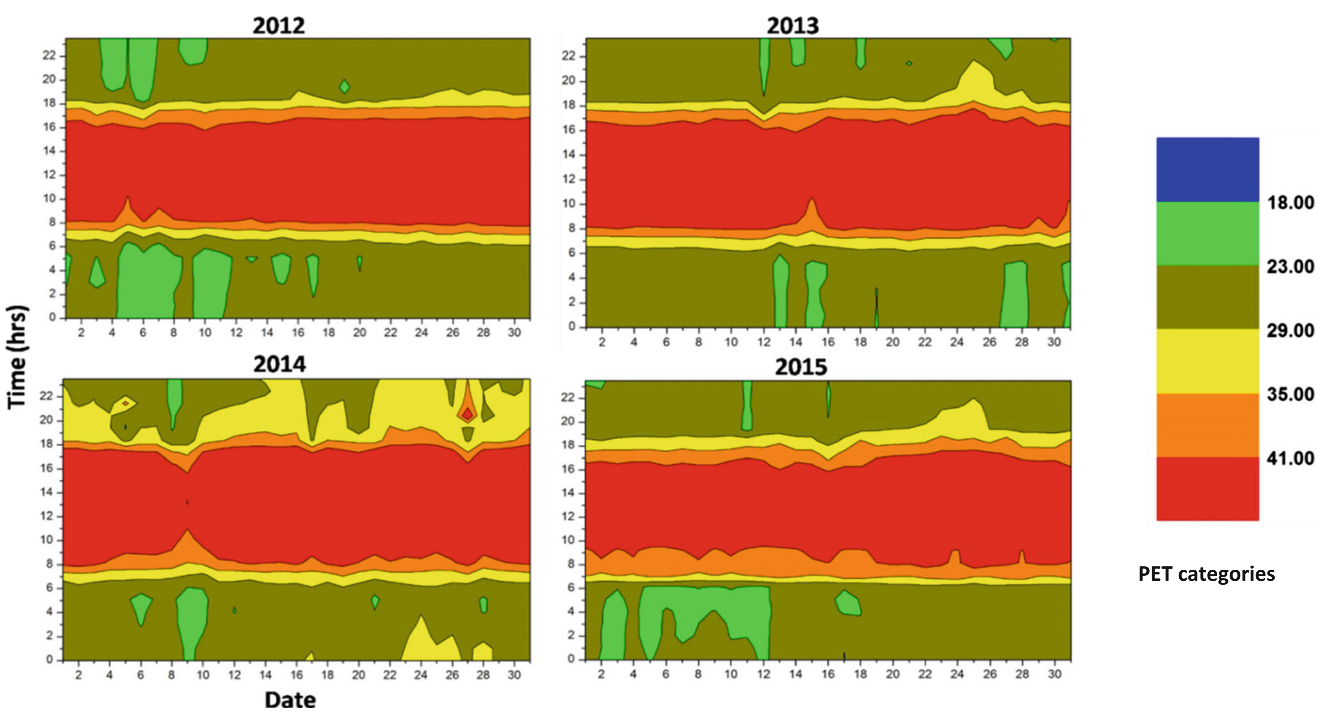

Fig. 6 PET (°C) over Srikakulam District of Andhra Pradesh during May

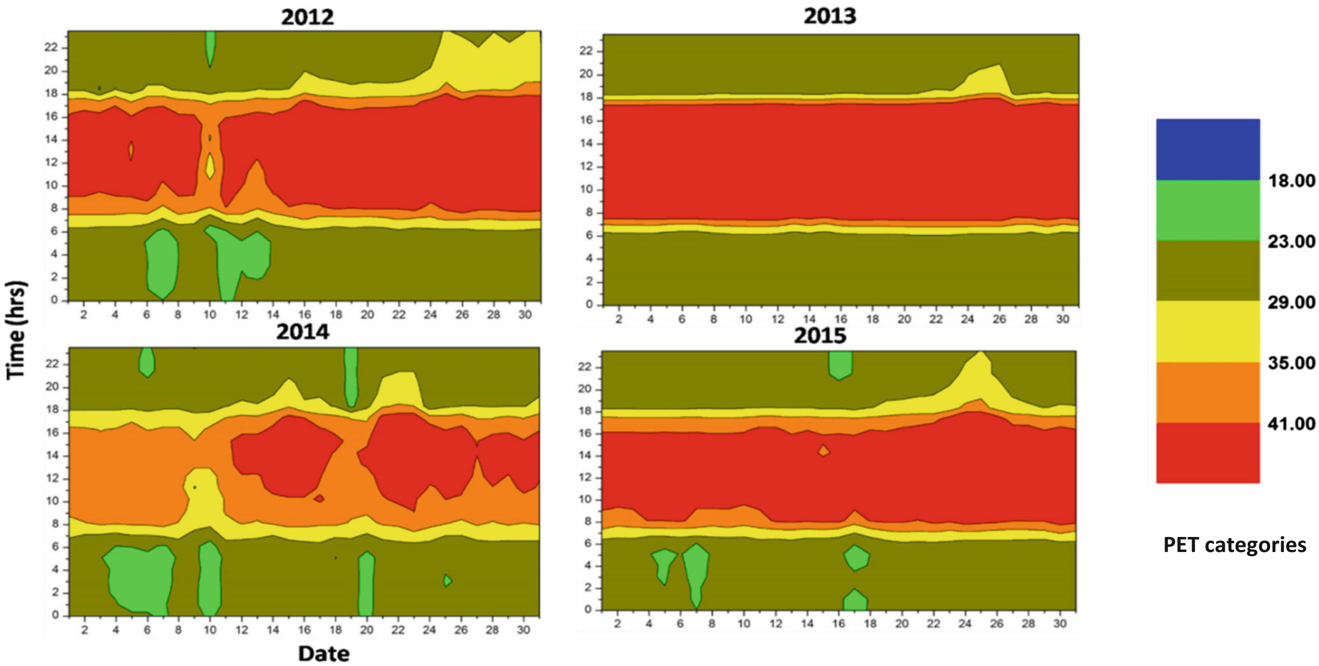

Fig. 7 PET (°C) over Undi District of Andhra Pradesh during May

under the curve of PET >41 and the number of deaths reported. At Undi, there was a sudden increase in the area under the curve of PET > 41°C during 22–26 May, which decreased thereafter (Fig. 11). The peak of area under the curve occurred on 24–26 May, and deaths reported on 26 and 27 May were 13 and 15, respectively, which means that there was a time lag of 2 days.

Discussion

Though plenty of heat-wave-related mortality studies are available from India (Azhar et al. 2014; Murari et al. 2014; Desai et al. 2015; Chaudhury et al. 2000), all of them considered daily temperature data to estimate the intensity and duration of heat waves. The present work has used half-hourly weather data from AWS to estimate the PET values by which analysis of temporal variation in heat stress conditions in sub-hour interval was made possible. This is a significant improvement in the area of research on heat wave impact on human death rate in India. The results of Srikakulam and Undi look promising, while that of Anantapur and Kurnool was different. Srikakulam and Undi are located close to the sea (Bay of Bengal) compared to Anantapur and Kurnool, which are inland regions. High humidity near coastal areas might have aggravated the number of deaths due to heat wave conditions

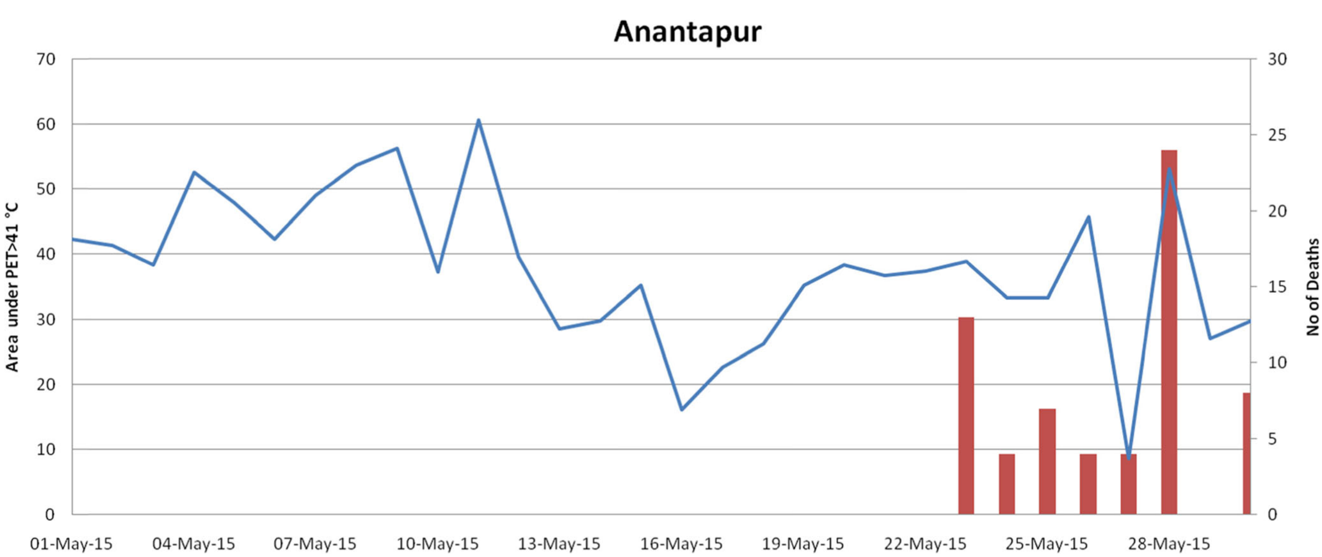

Fig. 8 Area under the curve (PET >41) and daily death rate at Anantapur in May 2015

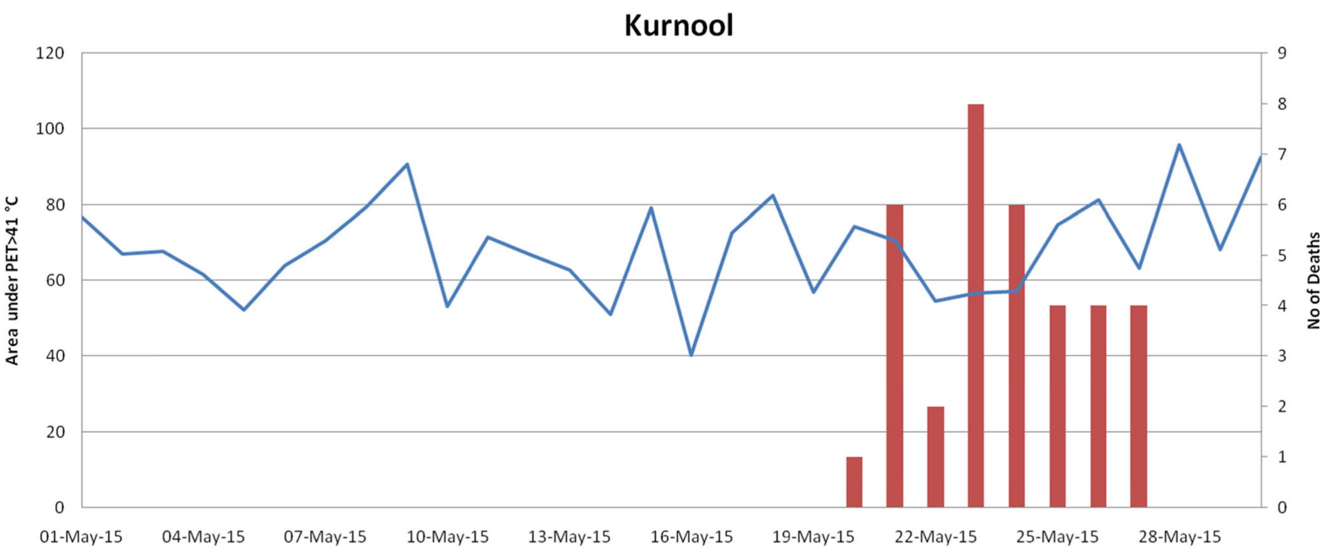

Fig. 9 Area under the curve (PET >41) and daily death rate at Kurnool in May 2015

persisted during May 2015. From the details of study locations given earlier, it is clear that normal relative humidity during second fortnight of May is much higher at Srikakluam (80%) and Undi (67%), compared to Ananatapur (48%) and Kurnool (46%). Desai et al. 2015 also recommended that humidity values should be considered while calculating mortality due to heat waves. This is well reflected in the area under the curve method discussed earlier. But, being inland areas, humidity might have not played a crucial role at Anantapur and Kurnool. Moreover, being an arid region, people will be more resilient toward high temperature during summer.

We observed that there was a lag time of 2 days between the peak of heat stress and death rate at Undi. On analyzing heat wave impact of May 2010 at Ahmedabad City, India, Azhar et al. 2014 had reported about the concurrency of increase in temperatures and mortality, i.e., there was no apparent lag time from increase in temperature to the increase in mortalities. This difference may be due to the consideration of area under the curve of PET >41 (which considers temperature, relative humidity, and wind speed during half-hourly intervals, whereas Azhar et al. considered only daily temperature values). The delay in reporting the death may also be another possible reason.

The present work has many limitations. Though PET is a better tool for assessing the impact of heat stress on death rate, there are assumptions for the estimation of the same, which was discussed in the methods section. It does not discriminate gender, age, etc. The resilience of human being to heat stress will vary according to gender, age, geographical location, nature of occupation, type of clothing, etc., to name a few. PET is

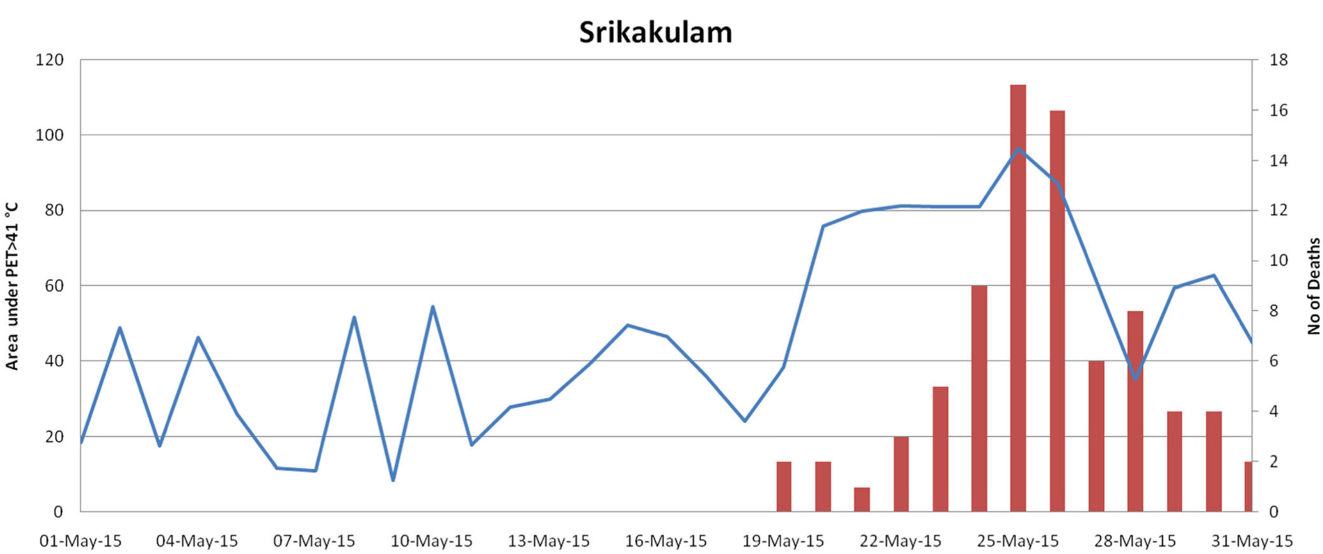

Fig. 10 Area under the curve (PET >41) and daily death rate at Srikakulam in May 2015

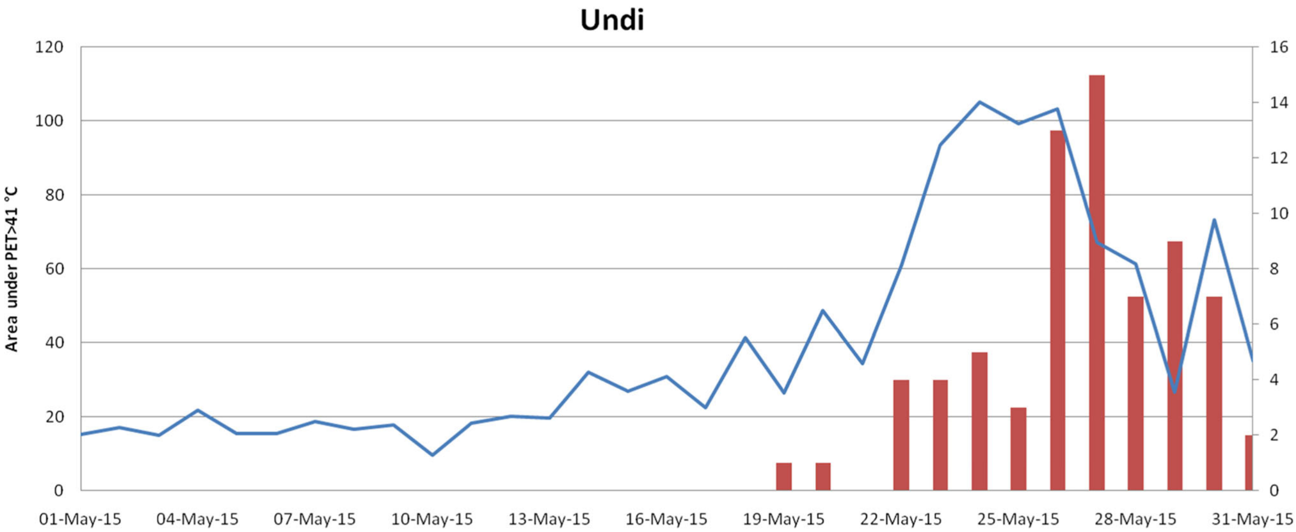

Fig. 11 Area under the curve (PET >41) and daily death rate at Undi in May 2015

estimated for a reference person (male, aged 35, undertaking indoor work, and having a clothing factor of 0.9 clo (1 clo = 0.155 K/m^2/W).

The range of PET values for different heat stress classes is another point of concern. Though the index is of universal application, the same values cannot be applied to an arid region and humid or per-humid region. For example, for a place with a maritime climate (like Srikakulam and Undi, where humidity also plays a significant role), PET values greater than 41 may cause extreme heat stress. But, for an arid place like Anantapur, the actual values may be higher. That may be the reason why we could not get proper relation between the area under the curve of PET >41 and the death rates.

No correlation studies were attempted in this study between the area under the curve of PET >41 and the death rates considering the fact that correlation in an ecological analysis alone does not indicate cause (Azhar et al. 2014). Our main aim was to estimate the intensity and duration of heat stress caused due to heat waves and compares it with the death rates.

In spite of all the above-mentioned concerns, the results of this analysis provided interesting insights into the diurnal variation of heat load for a location. The ultimate aim of such kind of work will be the development of early warning systems. Existing heat warning systems consider less specific local or regional weather information. In India, mainly daily temperature is the sole parameter used for the same. We hope that this methodology can be adopted to find out the areas (in spatial domain) and time of the day (in temporal domain) in which heat wave impact causes more deaths. At the same time, this study also points to the necessity to modify the criteria adopted by IMD in defining heat wave, which is only based on temperature. As opined by Azhar et al. 2014, present IMD definition of heat wave may underestimate the impacts of extreme heat load on human health because it does not consider the physiological aspect of heat wave and the role of other weather elements like relative humidity and wind speed. This work also point out the importance of analyzing extreme events like heat waves with hourly or half-hourly weather parameters, rather than with daily temperature values alone.

Conclusion

The heat waves of May 2015 have caused 1677 deaths in the state of Andhra Pradesh alone. The heat wave characterization using PET revealed that extreme heat load conditions (PET >41) existed in all the four locations throughout May during 2012–2015, with varying intensity. Another alarming finding is that the comfortable hours (no thermal stress) were very less in all the locations, which allow the humans to relieve the heat stress caused during day time. The intensity and duration of heat waves characterized by “area under the curve” method showed good results for Srikakulam and Undi locations. One of the major features of this work is the use of half hourly AWS data in PET estimation. This provided variation of PET in half hourly interval. Such kind of information will help in fixing thresholds for defining heat waves, designing early warning systems, etc.

Way forward

As mentioned earlier, heat waves are relative to a location’s climate. We tried to define the heat waves in four locations using standard threshold values of PET, which did not yield good results for Anantapur (arid climatology) and Kurnool. More study is needed to establish location-specific threshold PET values to quantify the impact of heat waves on human death rate. Similar kind of work can be undertaken for studying the impact of cold wave on human death rate too.

References

Azhar GZ, Mavalankar D, Nori-Sarma A, Rajiva A, Dutta P, Jaiswal A, Sheffield P, Knowlton K, Hess JJ (2014) Heat related mortality in India: excess all-cause mortality associated with the 2010 Ahmedabad heat wave. PLoS One 9(3):1–8

Blazejczyk K, Epstein Y, Jendritzky G, Staiger H, Tinz B (2012) Comparison of UTCI to selected thermal indices. Int J Biometeorol 56:515–535

Chaudhury SK, Gore JM, Ray KCS (2000) Impact of heat waves over India. Curr Sci 79(2):153–155

Desai VK, Wagle S, Rathi SK, Patel U, Desai HS, Khatri K (2015) Effect of ambient heat on all-cause mortality in the coastal city of Surat, India. Curr Sci 109(9):1680–1686

Fanger PO (1970) Thermal comfort. Analysis and application in environment engineering. Danish Technical Press, Copenhagen

Gosling SN, Lowe JA, McGregor GR, Pelling M, Malamud BD (2008) Associations between elevated atmospheric temperature and human mortality: a critical review of the literature. Climate Change 92:299–341

Grigorieva EA, Matzarakis A (2011) Physiologically equivalent temperature as a factor for tourism in extreme climate regions in the Russian far east: preliminary results. Eur J Tour Hosp Recreat 2(3):127–142

Hoppe PR (1993) Heat balance modeling. Experientia 49:741–745

Höppe P (1999) The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71–75

IPCC (2014) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. Core Writing Team, Pachauri RK, Meyer LA (eds) IPCC, Geneva, Switzerland, 151 pp

Isaksen TB, Fenske RA, Hom EK, Ren Y, Lyons H, Yost MG (2016) Increased mortality associated with extreme-heat exposure in King County, Washington, 1980-2010. Int J Biometeorol 60:85–98

Keggenhoff I, Elizbarashvili M, King L (2015) Heat wave events over Georgia since 1961: climatology, changes and severity. Climate 3: 308–328. doi:10.3390/cli3020308

Kothawale DR, Kumar KK, Srinivasan G (2012) Spatial asymmetry of temperature trends over India and possible role of aerosols. Theor Appl Climatol 110:263–280

Matzarakis A, Amelung B (2008) Physiologically Equivalent Temperature as indicator for impacts of climate change on thermal comfort of humans. In: Thomson MC, Garcia-Herrera R, Beniston M (eds) Seasonal forecasts, climatic change and human health. Advances in global change research 30, Springer-Sciences and Business Media, pp 161–172

Matzarakis A, Mayer H (1997) Heat stress in Greece. Int J Biometeorol 41(1):34–39

Matzarakis A, Mayer H, Iziomon M (1999) Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorol 43:76–84

Matzarakis A, Rutz F, Mayer H (2000) Estimation and calculation of the mean radiant temperature within urban structures. In: de Dear RJ, Kalma JD, Oke TR, Auliciems A (eds) Biometeorology and urban climatology at the turn of the millenium: selected papers from the conference ICB-ICUC'99, Sydney, WCASP-50, WMO/TD No. 1026, 273–278

McGregor GR, Bessemoulin P, Ebi K, Menne B (2015) Heat waves and health: guidance on warning-system development. World Meteorological Organization-No. 1142, p 114

Murari KK, Ghosh S, Patwardhan A, Daly E, Salvi K (2014) Intensification of future severe heat waves in India and their effect on heat stress and mortality. Reg Environ Chang. doi:10.1007/s10113-014-0660-6

NCRB (2015) Accidental deaths and suicides in India-2014. National Crime Records Bureau. 322 pp

NDMA (2016) Guidelines for preparation of action plan-prevention and management of heat wave. National Disaster Management Authority, Government of India. P3

NIDM (2015) Disasters update. National Institute of Disaster Management (India). 31 May 2015. 4 pp

Parsons KC (2003) Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort and performance. Taylor and Francis, London 527 pp

Schaeffer L, Crouy-Chanel P, Wagner V, Desplat J, Pascal M (2016) How to estimate exposure when studying the temperature-mortality relationship ? A case study of the Paris area. Int J Biometeorol 60:73–83

Trigo R, Garia-Herrera R, Diaz J, Trigo I, Valente M (2005) How exceptional was the early august 2003 heat wave in France ? Geophys Res Lett 32:L10701

VDI (1998) Methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning. Part I: climate (p. 29). VDI-guideline 3787. Part 2. Beuth, Berlin