Heat wave fatalities over India: 1978–2014

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The present paper is an attempt to study the heat waves associated fatalities over space and time in India. For this, 'Disastrous Weather Events' reports statistics have been used for the period 1978–2014. The analysis has shown that a total of 660 heat wave events have caused 12,273 fatalities (about 332 fatalities every year). Only five states namely, Andhra Pradesh (42%), Rajasthan (17%), Odisha (10%), Uttar Pradesh (7%) and Bihar (7%) have accounted more than 80% of the heat wave fatalities, although nine states namely, Arunachal Pradesh, Nagaland, Manipur, Meghalaya, Tripura, Sikkim, Mizoram, Uttarakhand and Goa have never reported heat wave events and fatalities during 1978–2014. Interestingly, each event has resulted about 104 fatalities in Andhra Pradesh state. Further, fatality and density rates have been witnessed to the tune of 0.35 and 3.81 respectively. Temporally, heat wave events have displayed large differences with a significant increasing trend ($P < 0.01$), whereas no trend could be noticed in fatalities. Majority of events have been witnessed in May and June months. It has been observed that men have been more harshly affected compared to women and children. Finally, it is believed that this study may provide new insight towards making better disaster management guidelines for minimizing the shocks of harsh temperature.

Keywords: Disaster management, extreme temperature, fatalities, gender differences, heat wave.

EXTREME temperature related events particularly heat waves have been well-documented as the most hazardous atmospheric occurrences, resulting in large number of casualties[1]. Heat wave refers to a long duration of excessive heat particularly all along the summer season[2]. A heat wave accompanied by humidity poses a bigger threat to humans[3] and results in huge number of fatalities worldover[4]. In recent years, a rise in their occurrence, duration and intensity has been observed as a result of global warming[5]. With the increasing influence of anthropogenic factors on global climate, the frequency of intensified heat waves may increase further[6,7]. Since 1980s, heat waves have increased roughly 2.7 times at the global level and have emerged as a serious threat to humans[4].

In recent decades, some extreme heat wave events have resulted in thousands of deaths, attracting global attention. Heat waves account approximately 90% of the total extreme temperature events related fatalities[8]. During the summer season of 1980, about 10,000 deaths were reported owing to extreme heat in the United States[9]. In 1987, more than 2000 deaths were caused by a major heat wave event in Athens[10]. A heat wave event in Chicago during 1995 caused a total of 697 deaths and more than 3000 emergency department visits[11]. Similarly, heat wave episodes of Europe during 2003 resulted in tens of thousands of deaths[12]; in California during 2006 resulted in over 600 deaths and more than 16,000 hospital emergency department visits[13], Europe in 2006 resulted in 3418 fatalities[4]; Australia in 2009 resulted in 374 fatalities and 3334 illnesses[14]; Pakistan in 2015 resulted in 1200 fatalities[15]. Apart from these, several researchers have further examined heat wave related fatalities over European countries, United States and Australia[16–18]. Besides the human fatalities, heat waves lead to crops failures and wild fires, which subsequently affect various social activities[19].

India is a tropical country and frequently experiences severe heat wave conditions owing to its unique geographical and climatic set-up. Lately, global extreme temperature related fatalities have been examined, which revealed that India is the most severely affected country by heat waves in the world[4]. In India, heat wave conditions normally form between March and July months, which results in thousands of casualties every year[20]. The heat waves of 1998 have caused about 2600 fatalities; of 2002, about 1000 fatalities; 2003, about 1300 fatalities only in Andhra Pradesh and of 2015, about 2677 fatalities in Andhra Pradesh and Telangana states of India[20–23]. These studies were limited to an individual year, event and state, however, studies with respect to distribution of heat wave fatalities over India for a period range were completely lacking. Therefore, this study aims to examine heat waves occurrence and associated fatalities over space and time in India during the period 1978–2014. The findings of the study will help in evolving practical as well as operational risk management actions with respect to heat waves.

Data and methodology

The statistics of 31 states (comprising Union Territories) have been acquired from the yearly 'disastrous weather

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Table 1. Criteria to define a heat wave event from India Meteorological Department

Category	Normal temperature	Departure from normal	Intensity of heat wave
a	When normal temperature of a station is less than or equal to 40°C	5°C to 6°C	Heat wave
		7°C or more	Severe heat wave
b	When normal temperature of a station is more than 40°C	4°C to 5°C	Heat wave
		6°C or more	Severe heat wave

events' reports of the India Meteorological Department (IMD), Pune, for 1978–2014. These reports contain the statistics of several disasters, for example, heat and cold waves, floods and droughts, extreme rainfall, cyclones, lightning, hailstorm, etc. The statistics comprises of: (i) Date, month and year of the stated event; (ii) Place of occurrence (state and district); (iii) Demographic details of affected persons; (iv) Record of persons killed/injured; and (v) Record of livestock killed/injured. These statistics have been used frequently by researchers to investigate different disasters and their impacts over India[20,24–27].

Additionally, state-wise population and area statistics have been procured from Census of India records for the census years, i.e. 1981, 1991, 2001 and 2011. Using these records, yearly population have been computed for each state and India as a whole. Subsequently, the annual heat wave event/fatality rates and density have been computed using annual population and area statistics[26,27].

Description of heat wave

There is no universal description of extreme temperature events such as heat and cold waves. It is a challenging task to identify the beginning and ending time of an extreme temperature event, although, IMD has classified heat wave events into two groups based on departure of diurnal maximum temperature from the usual maximum temperature (Table 1).

Calculation of heat wave event and fatality rates

Heat wave event or fatality rates have been mathematically expressed as

$$R = [(N/P) \times 1{,}000{,}000]/n, \quad (1)$$

where R is the rate (per million population per year), N the sum total of heat wave events and fatalities reported, P the yearly sum total of population likely to be troubled (i.e. aforementioned population is the mean of decade-long census for census years, 1981, 1991, 2001 and 2011), and n is the sum total of years from 1978 to 2014.

Calculation of heat wave event and fatality density

Heat wave event and fatality density (per thousand sq. km) are expressed as

$$D = (N/A) \times 1000, \quad (2)$$

where D is the density (per thousand sq. km), N the sum total of heat wave events and fatalities reported and A is the area in sq. km with respect to an areal unit, i.e. the state or country.

Computation of change point detection by Pettitt's test

The Pettitt's is a non-parametric test, which has been employed widely to identify the abrupt changes in the time series data[28]. Therefore, to notice a change point in time-series of heat wave events and fatalities, Pettitt's test has been performed. This test is based on the rank and ignores the normality of the series. The ranks $r_1,\ldots, r_n$ of $x_i,\ldots, x_n$ are used to calculate the statistics. Statistically, it can be written as

$$Y(k) = 2\sum_{i=1}^{k} r_i - k(n+1),\ k = 1,2,3,\ldots,n. \quad (3)$$

The discontinuity happens at k observation where $Y(k)$ is maximum or minimum.

Later, the investigated statistics have been organized into tabular, graphical and spatial (maps) forms. For regional analysis, area of study, i.e. India has been partitioned into six regions[29]. States like Chhattisgarh, Jharkhand and Uttarakhand were constituted in 1999, therefore, these states have been contemplated independently in this study since 1978, by probing the locations of their administrative units, i.e. districts. Additionally, a simple linear regression has been executed to identify the significance level of trends of heat wave events and fatalities in India.

Results and discussion

Spatial variations

State-wise variations: Table 2 demonstrates the state-wise number, rate and density of heat wave events and fatalities with their ranks in India. Maximum count of events has been observed in Maharashtra state followed by Rajasthan, Odisha, West Bengal, Punjab and Andhra Pradesh, whereas, maximum fatalities have been

Table 2. Count, rate and density of heat wave events and fatalities with their ranks, for states (including union territories) of mainland India from 1978 to 2014

States	Population (million)	Area (km^2)	Events		Fatality		Event		Fatality		Event		Fatality	
			Number	Rank	Number	Rank	Rate	Rank	Rate	Rank	Density	Rank	Density	Rank
Andhra Pradesh	70.16	275,045	49	6	5119	**1**	0.019	10	1.972	**1**	0.178	12	18.611	**3**
Arunachal Pradesh	0.99	83,743	0	22	0	22	0.000	22	0.000	22	0.000	22	0.000	22
Assam	24.57	78,438	8	15	36	14	0.009	16	0.040	16	0.102	13	0.459	14
Bihar	75.88	94,163	31	9	885	**5**	0.011	15	0.315	6	0.329	8	9.399	**4**
Chandigarh	0.76	114	11	13	10	18	0.391	**1**	0.356	**4**	96.491	**1**	87.719	**1**
Chhattisgarh	19.5	135,192	8	16	22	15	0.011	14	0.030	17	0.059	19	0.163	17
Delhi	11.56	1,483	5	18	61	13	0.012	12	0.143	12	3.372	**2**	41.133	**2**
Goa	1.25	3,702	0	25	0	25	0.000	23	0.000	23	0.000	23	0.000	23
Gujarat	46.59	196,244	20	12	80	12	0.012	13	0.046	15	0.102	14	0.408	15
Haryana	19.06	44,212	28	11	113	11	0.040	**5**	0.160	10	0.633	**5**	2.556	11
Himachal Pradesh	5.6	55,673	4	19	11	17	0.019	9	0.053	14	0.072	17	0.198	16
Jammu and Kashmir	9.08	222,236	2	21	2	21	0.006	18	0.006	19	0.009	21	0.009	21
Jharkhand	24.84	79,716	35	8	288	8	0.038	6	0.313	7	0.439	7	3.613	10
Karnataka	48.99	131,791	6	17	6	19	0.003	20	0.003	20	0.046	20	0.046	20
Kerala	29.94	38,852	3	20	3	20	0.003	21	0.003	21	0.077	16	0.077	19
Madhya Pradesh	54.93	308,252	30	10	260	10	0.015	11	0.128	13	0.097	15	0.843	13
Maharashtra	87.71	307,713	89	**1**	472	6	0.027	7	0.145	11	0.289	9	1.534	12
Manipur	2.07	22,327	0	26	0	26	0.000	24	0.000	24	0.000	24	0.000	24
Meghalaya	2.1	22,429	0	23	0	23	0.000	25	0.000	25	0.000	25	0.000	25
Mizoram	0.79	21,081	0	27	0	27	0.000	26	0.000	26	0.000	26	0.000	26
Nagaland	1.49	16,579	0	28	0	28	0.000	27	0.000	27	0.000	27	0.000	27
Odisha	34.17	155,707	70	**3**	1197	**3**	0.055	**3**	0.947	**3**	0.450	6	7.688	**5**
Punjab	22.27	50,362	52	**5**	266	9	0.063	**2**	0.323	**5**	1.033	**3**	5.282	8
Rajasthan	50.87	342,239	86	**2**	2037	**2**	0.046	**4**	1.082	**2**	0.251	10	5.952	6
Sikkim	0.47	7,096	0	29	0	29	0.000	28	0.000	28	0.000	28	0.000	28
Tamil Nadu	59.63	130,060	9	14	19	16	0.004	19	0.009	18	0.069	18	0.146	18
Tripura	2.92	10,486	0	30	0	30	0.000	29	0.000	29	0.000	29	0.000	29
Uttar Pradesh	150.7	240,928	48	7	917	**4**	0.009	17	0.164	9	0.199	11	3.806	9
Uttarakhand	7.85	53,483	0	24	0	24	0.000	30	0.000	30	0.000	30	0.000	30
West Bengal	73.56	88,752	66	**4**	469	7	0.024	8	0.172	8	0.744	**4**	5.284	7
India (Total)	941.2	3,218,588	660		12273		0.019		0.352		0.205		3.813	

Boldface font indicates the top five ranking states.

recounted in Andhra Pradesh accompanied by Rajasthan, Odisha, Uttar Pradesh, Bihar and Maharashtra. Prevalence of a semi-permanent trough from Odisha to Tamil Nadu coast usually causes hot and dry north/north westerly winds leading to significant rise in temperature and subsequently heat-wave conditions[22]. Similarly, Raghavan[30] found that the subsidence of air, dry continental westerlies, scarce vegetal cover and ample dust particles being responsible for high temperatures over western states. The maximum count of heat wave events has been detected in northwest (30%) followed by central northeast (28%) and central west (19%) regions, whereas least over hilly (1%) followed by peninsula (10%) and northeast (11%) provinces. Conversely, peninsula has experienced roughly 42% of the total fatalities followed by central northeast (27%) and northwest (21%) regions, while hilly region accounts almost negligible fatalities followed by northeast (4%) and central west (6%). Remarkably, the peninsula observed highest fatalities per event (77 fatalities). The state of Andhra Pradesh has attained the topmost rank in relation to the count of fatalities per event (roughly 104 fatalities) (Table 2). Such large number of fatalities over a state can be attributed to higher advection of hot and parched wind from the west and northwest and contrasting sea breeze alongside the coast which results in assemblage of heat, thereby escalating the heat wave conditions[19]. Furthermore, the states like Arunachal Pradesh, Nagaland, Manipur, Meghalaya, Tripura, Sikkim, Mizoram, Uttarakhand and Goa have never witnessed heat wave events and fatalities during 1978–2014.

Variations by states weighted by population: The heat wave events and fatalities rate per million population per annum have been found to be 0.02 and 0.35 respectively (Table 2). Chandigarh has witnessed highest heat wave event rate followed by Punjab, Odisha, Rajasthan and Haryana. While Andhra Pradesh has the maximum fatality rate per million population per year followed by Rajasthan, Odisha, Chandigarh and Punjab state. The annual heat wave event rate was found in northwest and central west regions. Fatality rate varies from 0.66 (peninsula region) to 0.02 (hilly region) per annum.

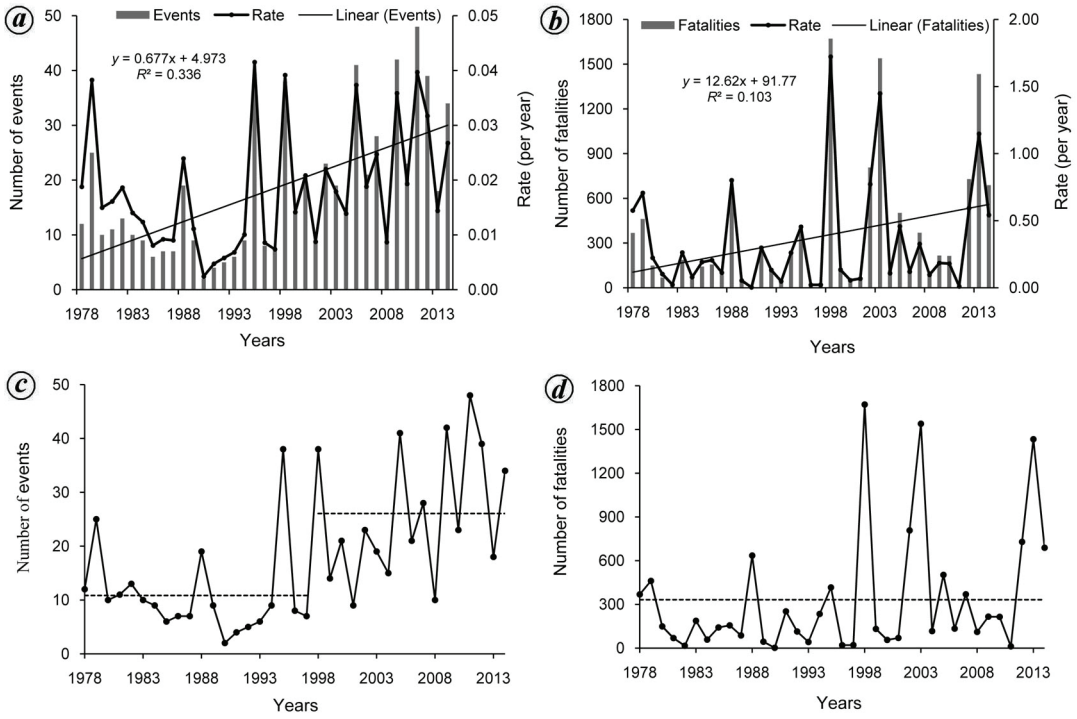

Figure 1. Yearly number and rate per million of population of heat wave (***a***) events and (***b***) fatalities with their change point detection; (***c***) events and (***d***) fatalities for the period 1978–2014.

Variations by states weighted by area: The heat waves event and fatality density per thousand sq. km area were observed to the tune of 0.02 and 3.80 respectively, for India (Table 2). In this case also, Chandigarh has reported highest event density followed by Delhi, Punjab, West Bengal and Haryana. Likewise, Chandigarh has the topmost fatality density accompanied by Delhi, Andhra Pradesh, Bihar and Odisha. Greater heat waves fatality density in Chandigarh and Delhi may be ascribed to excessive population concentration in these small sized urban areas. The lowest heat wave events and fatality density have been detected in the hilly region, while, the highest in central northeast and peninsula provinces respectively.

Temporal variations

Year-wise variations: Figure 1 *a* and *b* displays the fluctuations in yearly count and rate of heat wave events and fatalities reported in the country. The count of heat wave events ($P < 0.01$) has shown a significant rising trend. However, no significant rising and falling trend have been observed in heat wave fatalities in the country during 1978–2014. The increase in mean annual temperature at the rate of 0.22°C per decennium in India might be the major cause for increase in heat waves[31]. Figure 1 *c* and *d* represent the results of abrupt change point detection in heat wave events and fatalities time series. It has been observed from the analysis that a change in heat wave events has been witnessed from 1997, significant at 99% confidence level. Meanwhile, annual heat wave fatalities distribution has been found homogeneous. A total of 660 heat wave events have resulted in 12,273 fatalities with a mean of 18 events and 332 fatalities per annum. The maximum count of heat wave events has been observed during 2011 (48) and highest number of fatalities in 1998 (1671), while minimum number of events and fatalities have been detected during 1990 (two each). It has been observed that most of the high fatality years are associated with El Niño years[32]. Moreover, each event has resulted in roughly 19 fatalities with large annual fluctuations that vary from a humble 0.25 fatalities per event in 2011 to reach as high as 80 fatalities per event in 2013. Interestingly, 48 events of 2011 have caused only 12 fatalities, whereas 18 events of 2013 have caused 1433 fatalities. Similarly, in 1991, only 4 events have resulted in 252 fatalities.

The count and rate of heat wave events and fatalities have been found almost constant during the first two decades. However, the count and rate have increased drastically afterwards. Less number of heat wave fatalities during the last decennium may be ascribed to lesser count of years during this period. Moreover, all geographic regions of the country have shown an insignificant rising trend in the count of heat wave events (except central west and peninsula regions; $P < 0.01$). The heat wave events have occurred almost every year over northwest,

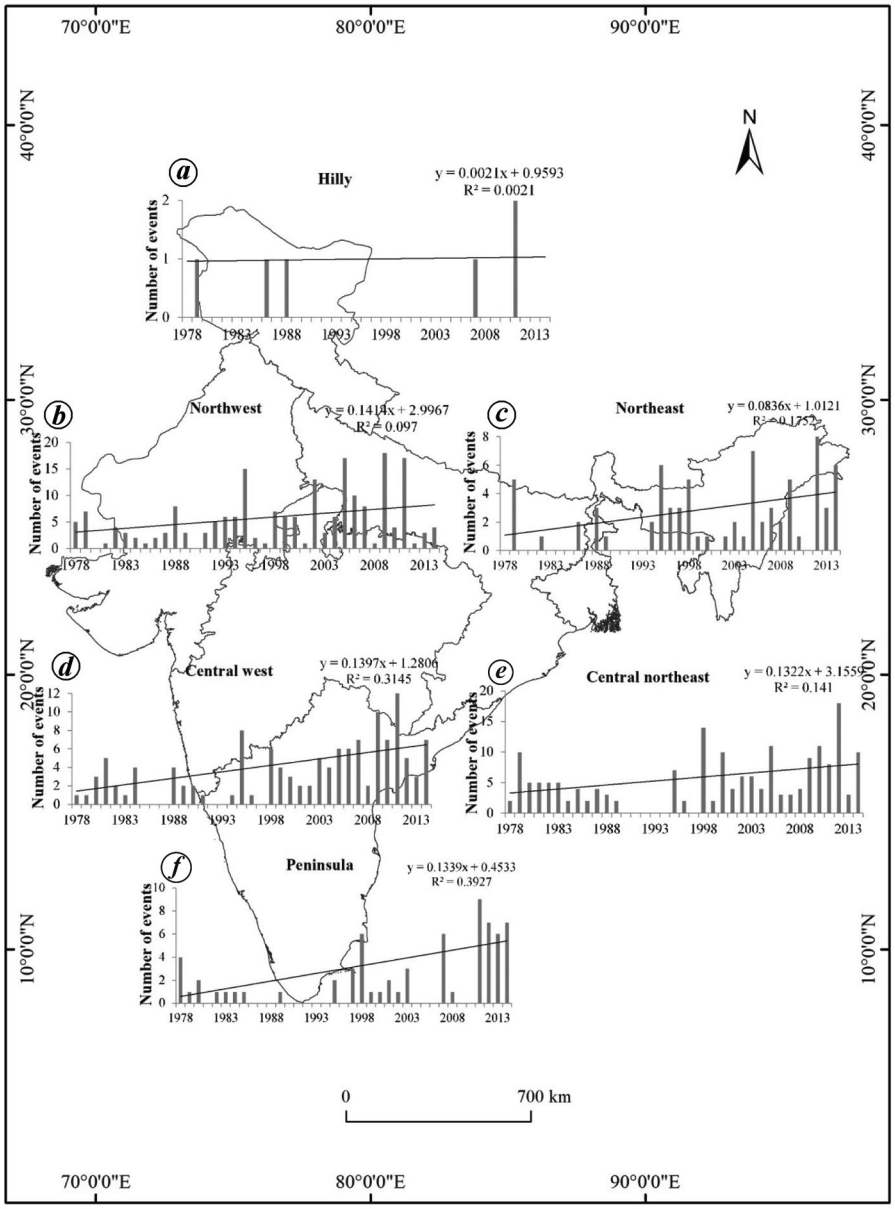

Figure 2. Region-wise yearly variations in count of heat wave events in India: (***a***) hilly, (***b***) northwest, (***c***) northeast, (***d***) central west, (***e***) central northeast and (***f***) peninsula from 1978 to 2014.

central west and central northeast regions, whereas their occurrence has been detected only in the last few years over the hilly region (Figure 2). In terms of region-wise fatalities, all the regions have shown slightly increasing or constant trend except northwest region (unusual decreasing trend). However, these trends have been found statistically insignificant (Figure not shown).

Monthly variations: Generally, temperature begins to increase rapidly from the month of March in India. The maximum temperature reaches at its peak in the month of May followed by April and June[33]. Extremely high temperature triggers heat wave conditions in these three months in the country. Nearly 43% of total events and 50% of the total fatalities have occurred alone in the month of May followed by June (roughly 31% events and 40% fatalities of the total) and April (about 20% events and 8% fatalities of the total). Although, May has a greater count of heat wave events than June, however, the number of fatalities per event is more in June (24) than May (21.5). Large amplitude of upper-level anticyclone, less cloud cover and strong dry north/northwesterly winds are responsible for significant increase in temperature, thereby resulting in heat wave conditions over India during these three months[34]. By late June, southwest monsoon sets in over large parts of the country and heat

waves condition starts to disappear resulting in only a few events during July and August months. Additionally, each geographical region has witnessed high heat wave events in the month of May except the central northeast (June). Conversely, heat wave fatalities are high in the month of June over most of the regions except the central west and peninsula (May). Besides, northwest and northeast regions have reported few heat wave events and fatalities in the month of August.

Gender variations

The analysis has shown large differences in gender-wise count of heat wave fatalities. Most of the heat wave fatalities have been witnessed among men. Whereas, fatalities among women (0.14%) and children (0.20%) have been found practically small. This may be ascribed to the higher participation of men in outdoor activities. Individuals employing outdoor activities, and who are socially cut off and economically deprived are exceedingly susceptible to causality as a result of natural disasters[26,27].

Top five heat wave events

In addition to huge difference in the heat wave fatalities over space and time, a single spell of heat wave has affected large number of people in some years. Table 3 shows the topmost five spells of such heat wave events in relation to fatalities resulted by them. These five heat wave events have resulted in approximately 25% of the total count of fatalities. About 1300 deaths have been reported during a heat wave spell lasting from 15 May to 14 June 2003 in Andhra Pradesh. Also, out of these five topmost events, three have occurred in Andhra Pradesh and one each in Odisha and Rajasthan.

Conclusion

The results of this study revealed a sum total of 12,273 fatalities, which have been caused by 660 heat wave events resulting in 332 fatalities annually during the 37-year period (1978–2014). The heat wave events have shown a rising trend ($P < 0.01$), whereas no significant rising or declining trend was observed in the heat wave fatalities. Majority of heat wave events and fatalities have occurred in the months of April, May and June. Maharashtra has experienced maximum count of events, while Andhra Pradesh has the highest count of fatalities. More than 80% of heat wave fatalities have occurred only in five states (Andhra Pradesh, Rajasthan, Odisha, Uttar Pradesh and Bihar). In relation to fatality rate per annum, topmost five states are Andhra Pradesh, Rajasthan, Odisha, Chandigarh and Punjab. In fatality density, topmost five states are Chandigarh, Delhi, Andhra Pradesh, Bihar and Odisha. Regionally, annual fatality rate has varied from 0.66 (peninsula region) to 0.02 (hilly region). A noticeable variation in the count of male fatalities over women and children has been detected. Higher male fatalities may be accredited to their higher involvement in outdoor works than women and children. Lastly, it is inferred that India is highly prone to heat waves and findings of this study may provide new insights towards the development of better strategies for preparedness and safety regarding heat waves. Also, more practical efforts are needed to understand the large-scale environmental factors that generate the heat wave conditions to reduce their impacts.

Table 3. Top five heat wave fatality events reported in India for the period 1978–2014

Spells	States	Fatalities
15 May–22 June 2003	Andhra Pradesh	1300
9–15 May 2002	Andhra Pradesh	600
1–31 May 1998	Andhra Pradesh	355
20–30 May 1998	Odisha	340
6–16 May 1988	Rajasthan	337

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Received 11 June 2019; revised accepted 27 January 2021

doi: 10.18520/cs/v120/i10/1593-1599