Ethiopian Journal of Environmental Studies & Management 19(4): 504 – 533, 2026
ISSN:1998-0507 doi: https://ejesm.org/doi/v19i4.9
Submitted: June 10, 2026 Accepted: July 6, 2026

LONG-TERM HEATWAVE TRENDS IN INDIA: 1967–2023

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Abstract

Heatwaves have increasingly emerged as a significant natural hazard in India, yet the absence of a comprehensive national dataset has limited our understanding of their frequency, distribution, and impact. This study aims to fill this knowledge gap by analyzing heatwave events and their associated impact across India from 1967 to 2023. Data were sourced from the Disastrous Weather Events reports published by the India Meteorological Department. The analysis examined temporal and spatial patterns, including month-wise, state-wise, and region-wise variations in heatwave events and fatalities. Key metrics—such as events, fatalities, event rate, fatality rate, event density, fatality density and fatalities per event—were assessed. A moderate positive correlation ($r = 0.311$, $p < .001$) was found between annual heatwave occurrences and fatalities. Hierarchical cluster analysis and scatter plot further revealed spatial and temporal clustering of heatwave impacts. The study also assessed secondary consequences, including illness, hospitalization, child fatality, animal deaths, crop losses, and water shortages. Additionally, the influence of El Nino and La Nina events was analyzed for the number of heatwave events and fatalities during, before, and after such events. The impact of the southwest monsoon on heatwave distribution is also discussed. Projections indicate an increase in heatwave events ($n = 43$) and fatalities ($n = 395$) by 2030. A comparative global overview confirms that heatwaves are becoming a major hazard worldwide. The findings underscore the urgent need for targeted mitigation strategies at local, national, and international levels to protect vulnerable populations and advance public health resilience in the face of climate change.

Keywords: *Climate extreme, Disaster, Climate change, Heatwave, India, Meteorological hazard*

Introduction

A disaster represents a significant disturbance in the operation of a society, resulting in extensive human, material, or environmental damage that surpasses the capacity of the affected community to manage using its own resources. Global disasters are categorized into two main types, with a considerable portion stemming from natural disasters. Various forms of natural disasters include droughts, earthquakes, heatwaves, floods, storms, volcanic eruptions, and wildfires. Meteorological and hydrological disasters collectively account for the largest share of natural disasters (Figure 1). In 2024, the Emergency Events Database (EM-DAT) documented 393 disasters related to natural hazards worldwide. These incidents resulted in 16,753 deaths and impacted 167.2 million individuals, with total economic damages reaching US$241.95 billion (CRED, 2025). As climate change continues to advance, heatwaves - a meteorological hazard are predicted to occur with greater frequency, duration, and intensity (Straits Times, 2025).

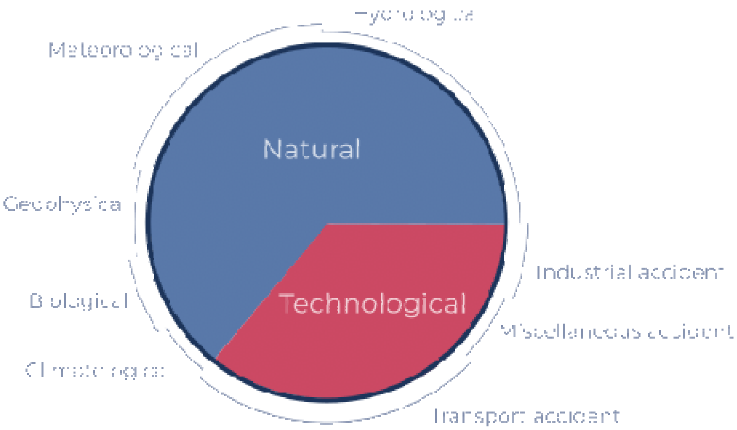

Fig. 1: Global disaster types (EM-DAT, 2023)

According to the World Meteorological Organization (WMO), a heatwave is described as "a period where local excess heat accumulates over a sequence of unusually hot days and nights." Heatwaves are characterized by an extended duration of unusually high temperatures, which can persist for days or even months, affecting both maximum and minimum temperatures in a given area. The occurrence of heatwaves has rapidly expanded into new areas globally and often happens at unexpected times of the year (WMO, 2025).

As stated in the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), climate change induced by human activities has heightened the frequency and severity of heatwaves since the 1950s, and further warming will continue to amplify these trends. A rise of 0.5°C in global temperature contributes to noticeable increases in the intensity and frequency of temperature extremes, including heatwave severity, occurrence, and duration. Heatwaves exacerbate the effects of drought, intensify wildfire conditions, create hazardous smoke, lead to water scarcity, cause power shortages, and result in agricultural losses, severely impacting communities worldwide. As global warming progresses, more populations will be exposed to heatwaves, with significant geographical disparities in heat-related fatalities affecting those with limited resources unless additional measures and adaptations are implemented (WMO, 2023).

In Greece, around 4,000 fatalities due to heatwaves were recorded in 1987. During the last major heatwave in the Nordic region in 2018, Sweden alone saw 750 deaths (Guardian, 2025a). That same year, more than 220 million at-risk individuals faced exposure to heatwaves. China experienced its longest recorded heatwave in 2022, lasting over 70 days. In 2022, severe heatwaves in India and Pakistan were made 30 times more probable due to climate change (WMO, 2025). The USA faced an unusual heatwave in June 2024, and in May 2025, China recorded temperatures surpassing 41°C. In 2024 and 2025, India coped with prolonged heat spanning 40 days. It is projected that heatwaves resulted in approximately 30,000 deaths worldwide in 2024 (Tourki, 2025).

The year 2024 was characterized by extreme temperature events throughout Asia. The Asian region, which is warming at nearly double the global average rate, has incurred losses of US$2 trillion (£1.5 trillion) attributed to extreme weather - including floods, heatwaves, and droughts - over the last thirty years, as reported by the annual Climate Risk Index survey (BBC, 2025). Heat poses a significant risk to vulnerable populations, including the elderly, individuals with health issues, pregnant women, infants, outdoor workers, and athletes. Urban environments can experience temperatures that are 5°C to 10°C hotter than surrounding areas, thereby increasing the intensity and associated dangers of heatwaves (WMO, 2025).

Nearly all regions of India are categorized within at least one natural hazard zone, and the socio-economic vulnerabilities make it one of the most disaster-prone nations globally. It faces considerable risks from floods, droughts, cyclones, earthquakes, landslides, avalanches, and wildfires. Of the 35 states and union territories in India, 27 are susceptible to disasters. Approximately 2% of India's gross domestic product is lost due to these natural disasters (MoHA, 2011).

The absence of a centralized statistical database documenting past disasters poses a significant barrier to risk evaluation and the compilation of disaster history in India. Various data sources provide differing casualty and impact figures, which complicates objective assessments. While scientific data on major hazards exist, information on vulnerabilities is dispersed across multiple sources and is often not uniformly available throughout the country. Disaster information from different entities has not yet been consistently evaluated by the general public or other stakeholders. Heatwaves are emerging as a significant natural disaster in India. The lack of comprehensive studies analyzing heatwaves in India highlights an existing knowledge gap in this field. To address this knowledge gap and contribute new insights, this study investigated long-term changes in heatwave frequency and associated impacts across India during 1967–2023.

Data and Methodology

Heatwaves Data

The primary data regarding heatwave events for the study period (1967-2023) were gathered from the annual 'Disastrous Weather Events' reports published by the Climate Research & Services division of the India Meteorological Department (IMD). These reports include information on the heatwaves, such as the date or duration, affected areas (states), intensity levels—Severe (A) and Severe (B), as well as details on casualties and the extent of damage caused. The casualty information encompasses illnesses or injuries, hospitalizations, and deaths among the local population during heatwave events. Additionally, fatalities of animals, including birds and fish, are documented. The damage extent includes losses in agriculture and shortages in the drinking water supply.

Moreover, population and area data by state were sourced from the Census of India for the years 1981, 1991, 2001, and 2011. Using these records, yearly population estimates have been derived for each state and for India as a whole. Subsequently, the annual occurrence rates of heatwave events and fatalities, as well as their density, have been calculated based on the annual population and area statistics. At the international level, data from EM-DAT, which has been compiled by the Centre for Research on the Epidemiology of Disasters (CRED) since 1987 (and dating back to 1900), was also consulted.

Criteria for Heatwaves

The IMD has established a set of criteria for recognizing heatwaves. This specific criterion has been in place since 1979. Table 1 outlines the criteria specified by IMD for categorizing heatwaves as moderate, severe (A), and severe (B). It is evident from the table that no explicit criteria for heatwaves were established during the early period from 1967 to 1978. Between 1979 and 1989, definitions for moderate and severe heatwaves were created based on day temperatures that exceeded normal levels. This criterion underwent further modifications in 1990 and remained in effect until 2015. During this time, terms such as heatwave, moderate heatwave, and severe heatwave were defined. In 2016, these criteria were revised again, broadening the scope to include heatwaves for plains, hilly stations, and coastal regions. Additionally, new stipulations were introduced for declaring a 'heatwave' during this period.

Table 1: Criteria to define heatwave events from India Meteorological Department

Duration	Normal temperature	Departure from normal	Intensity
1967-1978	No criteria		
1979-1989	-	Day temperature 6 to 7°C above normal	Moderate
	-	Day temperature ≥8°C above normal	Severe
1990-2015	Normal maximum temperature is 40°C or less.	Day temperature 5°C to 6°C above normal	Moderate
		Day temperature 7°C or more above normal	Severe
	Normal maximum temperature is more than 40°C	Day temperature 3° to 4°C above normal	Heatwave
		Day temperature 5°C or more above normal	Severe
2016 onwards*	Maximum temperature is at least 40°C or more for plains & at least 30°C or more for hilly stations	Departure from normal is 4.5°C to 6.4°C	Heatwave
		Departure from normal is greater than 6.4°C	Severe heatwave
	Actual maximum temperature is 37°C or more for coastal station	Maximum temperature departure from normal is 4.5°C or more	Heatwave
	When actual maximum temperature is greater than or equal to 45°C	-	Heatwave
	When actual maximum temperature is greater than or equal to 47°C	-	Severe heatwave

*For declaring ‘Heatwave’, the above criteria should be met at least in two stations in a meteorological subdivision, for at least two consecutive days, and it will be declared on the second day.

Calculation of Heatwave Event and Fatality rates

Mathematical expression [Eq. (1)] have been used to quantify heatwave occurrences or their associated fatality rates as

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

in this context, R represents the rate (calculated per million individuals annually), N denotes the cumulative number of reported heatwave incidents and related fatalities, P is the total annual population at risk (which is derived from the average of the census data taken over the decades for the years 1981, 1991, 2001, and 2011), and n signifies the total number of years spanning from 1967 to 2023 (Malik *et al*., 2021).

Calculation of heatwave event and fatality density

The occurrence of heatwaves and the density of fatalities (per thousand square kilometres) are represented as

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

in this context [Eq. (2)], D represents the density (measured per thousand square kilometres), N refers to the total number of reported heatwave occurrences and related fatalities, while A is the area measured in square kilometres, corresponding to a specific areal unit, such as a state or country (Malik *et al*., 2021).

El Nino and La Nina phenomenon

To evaluate the impact of the El Nino (warm) and La Nina (cool) phenomena in the eastern tropical Pacific on the frequency of heatwaves and related fatalities, data regarding the years of El Nino and La Nina and their intensities—classified as weak, moderate, strong, and very strong—were gathered based on the Oceanic Niño Index (Null, 2025). The text describes the 3-month running average of sea surface temperature (SST) anomalies for the Niño 3.4 region (which extends from 5°N to 5°S and 120°W to 170°W). Events are categorized into five consecutive overlapping 3-month periods that reach or exceed the +0.5°C anomaly for warm (El Nino) events, and at or below -0.5°C for cool (La Nina) events. This classification is further divided into Weak (with an SST anomaly of 0.5 to 0.9), Moderate (1.0 to 1.4), Strong (1.5 to 1.9), and Very Strong (≥ 2.0) occurrences.

Data Analysis

Statistical analyses were performed using IBM SPSS software (version 16.0) to investigate the relationship between heatwave events and associated fatalities in India. Pearson's correlation coefficient was applied to quantify the strength and direction of the association between the two variables. Analysis of Variance (ANOVA) and independent-samples t-tests were conducted to assess the statistical significance of differences observed across groups. Linear regression analysis was used to model the relationship and identify potential predictors of heatwave-related fatalities. A scatter plot was generated to visually represent the correlation between the annual heatwave events and the number of associated fatalities. To identify patterns and groupings within the data, hierarchical cluster analysis was employed, revealing clusters of time periods with similar heatwave event and fatality characteristics. Additionally, time series analysis was conducted to examine temporal trends and project future occurrences of heatwave events and related fatalities in India.

Results and Discussion

Historical Context of Heatwave Occurrence

This section provides a brief historical overview of heatwave occurrence in India based on archival records (1911–1967) available prior to the study period (1967–2023). It is included solely to provide historical context and is not part of the formal analyses presented in this study. All statistical analyses, including trend analysis, correlation, cluster analysis, and projections, are based exclusively on data for the period 1967–2023.

Table 2 summarizes heatwave occurrences in selected Indian states from 1911 to 2023. Data for the period 1911–1967 were obtained from the EM-DAT International Disaster Database, while records for 1968–2009 were sourced from the Ministry of Home Affairs report Disaster Management in India (MoHA, 2011). Data for the period 2010–2023 were extracted from the India Meteorological Department's Disastrous Weather Events reports. The pre-1967 records are presented only to illustrate the long-term historical distribution of heatwaves in India and are not included in the quantitative analyses undertaken in this study.

Table 2: Historical occurrence of heatwave events in selected Indian states (1911–2023)

State	1911-67	1968-77	1978-99	2000-2009	2010-23	1911-2023
West Bengal	31	2	28	6	32	99
Bihar	76	9	28	4	14	131
Uttar Pradesh	105	6	23	-	16	150
Rajasthan	27	3	42	14	19	105
Gujarat	43	1	7	2	11	64
Punjab	-	2	-	6	5	13
Himachal Pradesh	-	1	-	1	1	3
Jammu & Kashmir	-	-	-	-	1	1
Maharashtra	26	5	35	12	76	154
Madhya Pradesh	32	4	15	5	9	65
Odisha	25	8	18	22	122	195
Andhra Pradesh	21	-	3	2	56	82
Assam	-	4	19	-	1	24
Haryana	-	1	2	2	2	7
Tamil Nadu	5	-	2	1	4	12
Karnataka	-	-	-	1	4	5

(Updated from MoHA, 2011)

The analysis of heatwave events across selected Indian states reveals substantial temporal and spatial variability in frequency. A total of 1,110 heatwave events were recorded across the 16 states during the 112-year study period. A clear increasing trend in heatwave events is observed in recent decades. The most dramatic rise occurred during the period 2010–2023, with 490 events, accounting for 44.1% of all events in the dataset. This marks a fivefold increase compared to the previous decade (2000–2009), which recorded only 78 events.

The earlier periods (1911–1967) were marked by high heatwave activity in northern states, viz. Uttar Pradesh (105, 70%), Bihar (76, 58%), and West Bengal (31, 31%). Uttar Pradesh and Bihar states are adjacent to each other; thus, perhaps there may be a probability that a wide area heatwave may have covered both these states. The heatwaves in selected states in India (1911-2023) are in order of Odisha (195, 17.6%) > Maharashtra (154, 13.9%) > Uttar Pradesh (150, 13.9%) > Bihar (131, 11.80%). Together, these four states accounted for 57% of the total recorded events. Jammu & Kashmir had reported only one heatwave, followed by three in Himachal Pradesh and five in Karnataka (Table 2). These figures likely reflect the mitigating influence of topography and climate, such as higher elevations and tropical wet zones.

The data indicate a geographic shift in heatwave intensity, with north Indian states such as Uttar Pradesh, Bihar, and West Bengal experiencing more frequent events in the early to mid-20th century. In the 21st century, the central, eastern, and coastal regions - particularly Odisha, Maharashtra, and Andhra Pradesh - have emerged as new heatwave hotspots.

Overall, the findings indicate a statistically and environmentally significant shift in both the frequency and regional distribution of heatwave events in India. The sharp rise post-2010 aligns with global climate change trends and highlights the increasing vulnerability of states previously considered less affected. These findings underscore the urgent need for region-specific adaptation strategies and heat action plans, particularly in the most affected states.

Spatial Variation of Heatwaves

State-wise Variation

The state wise, heatwaves events, fatalities, rate, and density of fatalities per event are presented in Table 3 for the period of 1967 to 2023. From the table, it can be seen that the maximum number of heatwave events (n = 208) is observed in Odisha, followed by Maharashtra (n = 158), Andhra Pradesh (n = 108), Rajasthan (n = 105), and West Bengal (n = 88). The maximum (n = 8329) heatwave-induced fatalities are recorded in Andhra Pradesh (including Telangana), followed by Rajasthan (n = 2063), Uttar Pradesh (n = 1795), Bihar (n = 1746), and Odisha (n = 1386). The prevalence of a semi-permanent trough from Odisha to the Tamil Nadu coast usually causes hot and dry north / north-westerly winds, leading to a significant rise in temperature and subsequently heatwave conditions (Hema Malini *et al*., 2016). The subsidence of air, dry continental westerlies, scarce vegetal cover, and ample dust particles are responsible for high temperatures over western states (Raghavan, 1966). The states of Manipur, Mizoram, Nagaland, Sikkim, and Tripura have never witnessed heatwave events and fatalities associated with the study period under consideration. In case of states viz. Arunachal Pradesh, Goa, Meghalaya, and Uttarakhand had reported one heatwave event each. The Jammu and Kashmir (including Ladakh) had reported two heatwave events (Table 3).

Regional analysis of heatwave characteristics across India reveals distinct spatial variability in both event frequency and associated fatalities. Andhra Pradesh (including Telangana) has emerged as a prominent hotspot with the highest fatality numbers, fatality rate, and fatalities per event, indicating severe human impact during heat wave occurrences. The Union Territory of Chandigarh shows the highest event rate and event density, reflecting a greater concentration of heatwave events within a smaller spatial extent. Among the major meteorological regions, the peninsular region has been identified as a major hotspot for fatality numbers, fatality rate, and fatalities per event. The northwest region records the highest event rate and fatality density, while the central–northeast region shows relatively higher event numbers and event density. When the coastal states are considered collectively, the region exhibits the highest values for heatwave event numbers, fatality numbers, fatality rate, event density, and fatalities per event. These results indicate that coastal areas, along with parts of peninsular and northwestern India, are increasingly vulnerable to extreme heat conditions, consistent with the observed national trend of rising heat wave frequency and intensity (IMD and ICCS, 2024).

Table 3: Spatial variation of heatwave events, fatalities, and density in India

	Population	Area	Events		Fatality		Events		Fatality		Events		Fatality		Fatality/Event	
State	(million)	(sq. km)*	Number	Rank	Number	Rank	Rate	Rank	Rate	Rank	Density	Rank	Density	Rank	Number	Rank
Andhra Pradesh	70.16	275,045	108	3	8329	1	0.0270	8	2.083	1	0.393	11	30.282	3	77.120	1
Arunachal Pradesh	0.99	83,743	1	22	0	21	0.0177	11	0.000	21	0.012	24	0.000	21	0.000	21
Assam	24.57	78,438	8	18	36	15	0.0057	21	0.026	17	0.102	19	0.459	16	4.500	11
Bihar	75.88	94,163	56	8	1746	4	0.0129	16	0.404	4	0.595	7	18.542	4	31.179	2
Chandigarh	0.76	114	11	16	7	20	0.2539	1	0.162	8	96.491	1	61.404	1	0.636	20
Chhattisgarh	19.5	135,192	17	14	35	16	0.0153	12	0.031	16	0.126	17	0.259	18	2.059	16
Delhi	11.56	1,483	9	17	61	13	0.0137	14	0.093	12	6.069	2	41.133	2	6.778	6
Goa	1.25	3,702	1	23	0	22	0.0140	13	0.000	22	0.270	14	0.000	22	0.000	22
Gujarat	46.59	196,244	26	12	184	10	0.0098	18	0.069	14	0.132	15	0.938	14	7.077	5
Haryana	19.06	44,212	35	11	124	12	0.0322	5	0.114	11	0.792	6	2.805	11	3.543	15
Himachal Pradesh	5.6	55,673	6	20	24	17	0.0188	10	0.075	13	0.108	18	0.431	17	4.000	14
Jammu and Kashmir	9.08	222,236	2	21	0	23	0.0039	22	0.000	23	0.009	25	0.000	23	0.000	23
Jharkhand	24.84	79,716	45	9	287	8	0.0318	6	0.203	7	0.565	9	3.600	10	6.378	8
Karnataka	48.99	131,791	7	19	10	19	0.0025	24	0.004	20	0.053	21	0.076	20	1.429	19
Kerala	29.94	38,852	23	13	41	14	0.0135	15	0.024	18	0.592	8	1.055	13	1.783	17
Madhya Pradesh	54.93	308,252	39	10	166	11	0.0125	17	0.053	15	0.127	16	0.539	15	4.256	12
Maharashtra	87.71	307,713	158	2	643	6	0.0316	7	0.129	9	0.513	10	2.090	12	4.070	13
Manipur	2.07	22,327	0	26	0	24	0.0000	26	0.000	24	0.000	26	0.000	24	0.000	24
Meghalaya	2.1	22,429	1	24	0	25	0.0084	19	0.000	25	0.045	22	0.000	25	0.000	25
Mizoram	0.79	21,081	0	27	0	26	0.0000	27	0.000	26	0.000	27	0.000	26	0.000	26
Nagaland	1.49	16,579	0	28	0	27	0.0000	28	0.000	27	0.000	28	0.000	27	0.000	27
Odisha	34.17	155,707	208	1	1386	5	0.1068	2	0.712	2	1.336	3	8.901	5	6.663	7
Punjab	22.27	50,362	62	7	280	9	0.0488	3	0.221	5	1.231	4	5.560	9	4.516	10
Rajasthan	50.87	342,239	105	4	2063	2	0.0362	4	0.711	3	0.307	12	6.028	7	19.648	4
Sikkim	0.47	7,096	0	29	0	28	0.0000	29	0.000	28	0.000	29	0.000	28	0.000	28
Tamil Nadu	59.63	130,060	13	15	20	18	0.0038	23	0.006	19	0.100	20	0.154	19	1.538	18
Tripura	2.92	10,486	0	30	0	29	0.0000	30	0.000	29	0.000	30	0.000	29	0.000	29
Uttar Pradesh	150.7	240,928	66	6	1795	3	0.0077	20	0.209	6	0.274	13	7.450	6	27.197	3
Uttarakhand	7.85	53,483	1	25	0	30	0.0022	25	0.000	30	0.019	23	0.000	30	0.000	30
West Bengal	73.56	88,752	88	5	508	7	0.0210	9	0.121	10	0.992	5	5.724	8	5.773	9
India (Total)	941.2	3,218,588	1096	-	17,745	-	0.0204	-	0.331	-	0.341	-	5.513	-	16.191	-

*Data from the Census of India 2011

The frequency of heat wave days in India has exhibited a marked increase over recent decades, indicating a clear intensification of extreme temperature events. According to a joint study conducted by the IMD and the Institute for Climate Change Studies (ICCS), Kottayam, the total number of heat wave days across the country rose from 413 days during 1981–1990 to 575 days during 2001–2010, and further to 600 days during 2010–2020 (IMD & ICCS, 2024). This represents an approximate 45% increase in heat wave frequency over the past four decades. The temporal progression suggests a sustained and accelerating trend in the occurrence of extreme heat, consistent with broader regional and global warming patterns (Mukherjee *et al*., 2022; IPCC, 2023). These findings highlight the growing impact of the ongoing climate crisis on India's thermal regime and underscore the need for enhanced heat adaptation and mitigation strategies in vulnerable regions.

The maximum (n = 375) count of heatwave events has been detected in central northeast (35%), followed by northwest (n = 248, 23%) and central west (n = 198, 18%) regions, whereas least in hilly (n = 9, 1%) followed by northeast (n = 98, 9%) and peninsular (n = 151, 14%) regions. Conversely, the peninsular region has experienced about 47% (n = 8400) of total fatalities, followed by the central northeast (n = 5214, 29%) and northwest (n = 2719, 15%) regions. The negligible fatalities (n = 24) are reported from the hilly region, followed by the northeast (n = 544, 3%) and the central west (n = 809, 5%). The coastal states of India have reported 39% (n = 424) of total heatwave events, which result in 55% (n = 9735) of fatalities (Table 4).

Table 4: Region-wise yearly variations in event rates, fatality rate, event density, and fatality density in India (1967-2023)

Region (States)	Events number	Fatality number	Event rate	Fatality rate	Event density	Fatality density	Fatality/ Event
Hilly (Himachal Pradesh, Jammu & Kashmir, Uttarakhand)	9	24	0.0248	0.0751	0.1354	0.4310	4
Northwest (Chandigarh, Delhi, Haryana, Gujarat, Punjab, Rajasthan)	248	2719	0.3946	1.3696	105	118	42
Central Northeast (Bihar, Jharkhand, Odisha, Uttar Pradesh)	375	5214	0.1592	1.5269	2.769	38	71
Northeast (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, West Bengal)	98	544	0.0527	0.1468	1.1500	6	10
Central West (Goa, Madhya Pradesh, Maharashtra)	198	809	0.0580	0.1816	0.9101	2	8
Peninsular (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu)	151	8400	0.0468	2.1161	1.1377	32	82
Coastal states (Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Tamil Nadu, West Bengal)	424	9735	0.1232	2.4352	3.0453	40	99

Variation by States Weighted by Population

The heatwave events and fatality rate per million population per year have been presented in Table 3 and found to be 0.02 and 0.33, respectively, for India. From the table, it can be seen that the maximum (0.2539) event rate was observed in Chandigarh, followed by Odisha (0.1068), Punjab (0.0488), Rajasthan (0.0362), and Haryana (0.0322). In case of fatality rate, Andhra Pradesh has reported the maximum (2.083), followed by Odisha (0.712), Rajasthan (0.711), Bihar (0.404), and Punjab (0.221). The region-wise heatwave event rate was found to be maximum in the northwest (0.3946) and the central northeast (0.1592). In the case of fatality rate, it varies from 2.1161 (peninsular region) to 0.0751 (hilly region). On comparison of the fatality rate of regions with coastal states of India, it is found that they have a fatality rate of 2.4352, which is higher than the maximum recorded in the peninsular region (2.1161) per annum (Table 4).

Variation by State Weighted Area

The heatwave events and fatality density per thousand square kilometre area were observed to be 0.341 and 5.513, respectively, for India (Table 3). In this case, Chandigarh has reported maximum heatwave event density (96.491), followed by Delhi (6.069), Odisha (1.336), Punjab (1.231), and West Bengal (0.992). In case of fatality density, Chandigarh reported maximum fatalities (61.404) followed by Delhi (41.133), Andhra Pradesh (30.282), Bihar (18.542) and Odisha (8.901) (Table 3). The maximum heatwave fatalities density in Chandigarh and Delhi may be ascribed to excessive population concentration in these small-sized urban areas. The region-wise maximum heatwave event density was recorded in northwest (105), followed by central northeast (2.769), and minimum (0.135) in the hilly region. In the case of fatality density, similar observations were recorded (Table 4).

Fatality/Event

The fatality resulted due to heatwave events have been presented in Table 3. From the table, it can be seen that Andhra Pradesh (including Telangana) had the maximum fatalities per event (77.12), followed by Bihar (31.17), Uttar Pradesh (27.19), Rajasthan (19.64), and Gujarat (7.07). Such a large number of fatalities in Andhra Pradesh (including Telangana) 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 the assemblage of heat, thereby escalating the heatwave conditions (Dodla et al., 2017). The region-wise fatalities per heatwave event were found to be maximum in the peninsular region (82), followed by the central northeast (71) and northwest (42). The minimum fatality per heatwave event was recorded in the hilly region (4), followed by the central west (8) (Table 4).

Temporal Variation of Heatwaves

Year-wise Variation and Fatalities

The year-wise (1967-2023) variation of heatwave events and fatalities associated with them is presented in Table 5 and depicted in Figure 2. Heatwave events and associated fatalities in India have shown considerable interannual variability over the study period. While data for several early years are incomplete or missing (particularly from 1967 to the mid-1970s), a clear increase in both the frequency and impact of heatwaves is observed from the 1990s onward. The earliest recorded high-fatality event occurred in 1972, with over 1,200 deaths associated with 30 heatwave events. The deadliest year on record was 2015, with 2,081 fatalities, followed by 1998 with 1,712 deaths and 2003 with 1,539 deaths. Other significant years include 2013 (1,433 deaths) and 2002 (806 deaths). The highest number of heatwave events was reported in 2016, with 58 events, while 2011 also recorded a high of 47 events, albeit with only 12 fatalities. From 2000 onward, the number of heatwave events has consistently remained high, often exceeding 20 events per year, reflecting a likely trend linked to climate change and increasing surface temperatures. The year 2023 saw as many as 53 events and 181 deaths, reaffirming the persistent and growing threat of extreme heat in India.

Table 5: Year-wise heatwave events and fatalities

Year	Heatwaves events	Fatalities
1967	3	ND
1968	1	ND
1969	ND	ND
1970	Many parts of India	>500
1971	ND	ND
1972	30	>1200
1973	ND	ND
1974	2	11
1975	18	43
1976	10	48
1977	NA	NA
1978	12	368
1979	29	461
1980	13	156
1981	10	75
1982	5	16
1983	7	187
1984	9	58
1985	4	142
1986	5	156
1987	6	87
1988	15	635
1989	10	44
1990	2	2
1991	4	252
1992	5	114
1993	6	42
1994	9	234
1995	36	412
1996	9	20
1997	9	21
1998	34	1712
1999	14	132
2000	21	55
2001	8	70
2002	23	806
2003	14	1539
2004	15	117
2005	40	503
2006	21	135
2007	29	419
2008	10	111
2009	43	216
2010	23	269
2011	47	12
2012	39	829
2013	19	1433
2014	35	548
2015	29	2081
2016	58	526
2017	38	375
2018	14	33
2019	41	504
2020	18	27
2021	Nil	Nil
2022	27	30
2023	53	181

ND – No Data

Figure 2 illustrates the annual number of heatwave events (black bars) and fatalities (green line) in India from 1970 to 2023. The low and sporadic activity is observed in both heatwave events and fatalities during the 1970s and 1980s, likely due to underreporting or lack of systematic documentation. From the mid-1990s onwards, there has been a marked increase in the frequency of heatwave events. It is further observed that several years after 2000 show 20 or more events, with a peak around 2016, where more than 55 events were documented. Significant spikes are seen in years like 1998, 2002, 2003, 2013, and 2015 - with 2015 showing the highest fatality count, exceeding 2,000 deaths. Despite many years of recording high numbers of events (e.g., 2011, 2016), fatalities remain relatively low in some of those years. In recent years (post-2015), the number of events remains consistently high, while fatalities show lower and more variable trends, indicating a possible decoupling between frequency and fatality. From the figure, a rising trend of heatwave events in India and associated fatalities with it can be observed. The increase in mean annual temperature at the rate of 0.22ºC per decade in India might be the major cause for the increase in heatwaves (Antics *et al*., 2013).

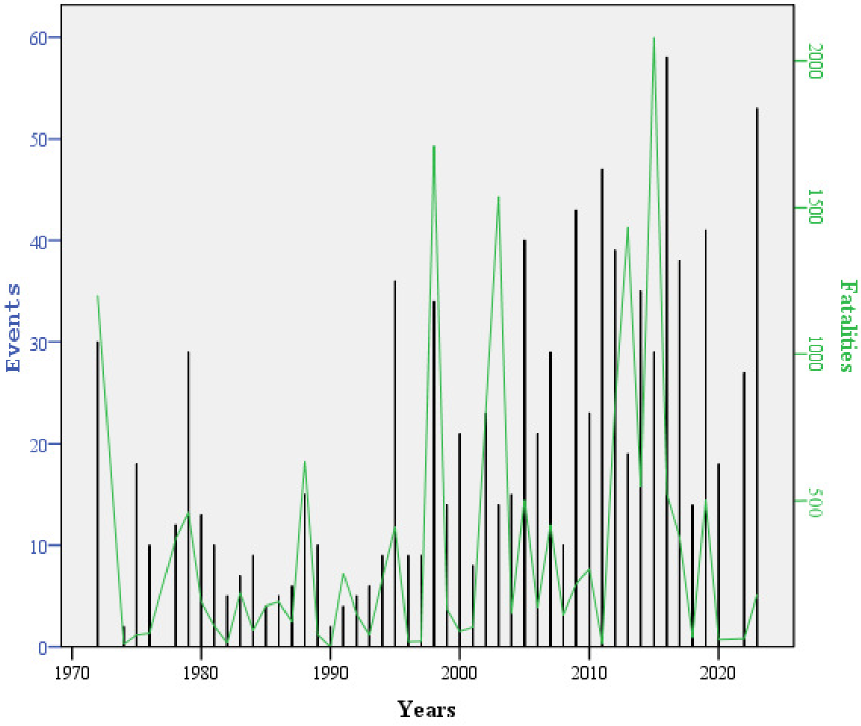

Fig. 2: Heatwave events and associated fatalities in India

A Pearson's correlation coefficient between heatwave events and fatalities was found ($r = 0.311$, $p < .001$). The heatwave events have shown a rising trend ($p < .001$), and a similar trend was observed for heatwave-induced fatalities ($p < .001$). The *p*-value between heatwave events and fatalities associated with it was ($p < .001$). The ANOVA (Analysis of variance) for heatwave events and fatalities was $F(1, 42) = 4.485$, $p < .05$, and therefore can conclude that the regression is statistically significant. The regression equation for heatwave-induced fatality was found to be 150.774+10.092 events. The *t* value for events ($t = 2.118$, $p < .05$) shows that the regression is significant.

The scatter plot (Figure 3) illustrates the relationship between the number of annual heatwave events and the corresponding number of fatalities in India. While a positive linear trend is observable, the correlation is weak, as indicated by a low coefficient of determination ($R^2 = 0.096$). This suggests that only about 9.6% of the variability in fatalities can be explained by the number of heatwave events alone. Most data points are concentrated in the lower left quadrant of the graph, with fewer than 20 events and fewer than 500 fatalities, indicating that smaller-scale heatwaves are more common. However, several outlier years show high fatality counts despite moderate event numbers, implying that event intensity, geographic coverage, or preparedness levels may play a more significant role in determining fatality outcomes than the event count alone. Although the frequency of heatwave events has generally increased over time, this scatter plot demonstrates that a higher number of events does not consistently translate to higher fatalities. The weak correlation highlights the importance of contextual factors, such as event severity, population exposure, adaptive capacity, and emergency response measures, in influencing fatality outcomes.

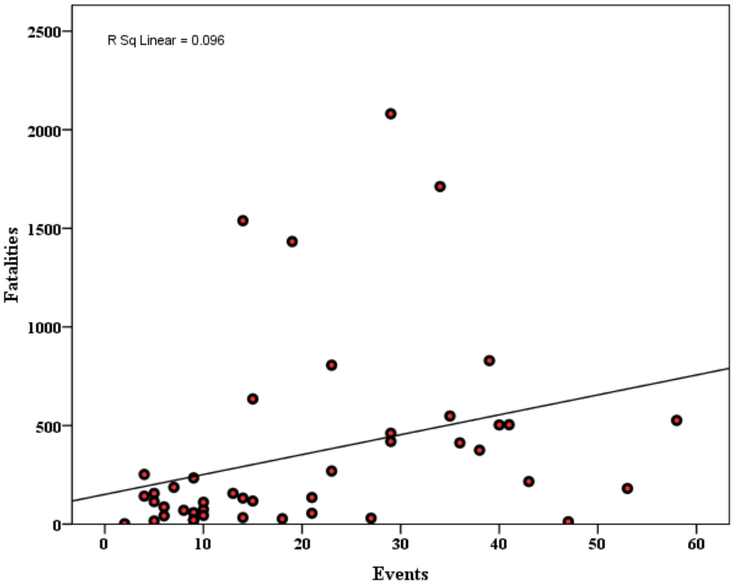

Fig. 3: Scatter plot of heatwave events and fatalities

Hierarchical cluster analysis was conducted using Ward's method with squared Euclidean distance to classify years based on heatwave event frequencies. The resulting dendrogram (Figure 4) reveals two principal clusters separated at a rescaled distance threshold of approximately 13, indicating significant temporal differentiation in heatwave occurrences over the study period. The first major cluster includes years characterized by low to moderate heatwave frequency, further divided into two sub-clusters. The first sub-cluster comprises 12 years exhibiting moderate heatwave events, including 2003 (n = 14), 2010 (n = 23), and 2013 (n = 19). The second sub-cluster consists of 17 years with relatively low heatwave events, such as 1986 (n = 5), 1990 (n = 2), 2001 (n = 8), and 2008 (n = 10). The second major cluster groups years with higher heatwave events and is subdivided into three distinct sub-clusters. A sub-cluster with two years—2016 (n = 58) and 2023 (n = 53)—which recorded the highest heatwave events in the dataset. These years correspond to extreme climatic anomalies, with 2016 documented as the warmest year globally at the time and 2023 declared by the WMO as the warmest year since the inception of instrumental records in 1850. A sub-cluster containing four years—1979, 2007, and 2015 (each n = 29 heatwave events), and 2022 (n = 27)—characterized by elevated heatwave occurrences. A sub-cluster with nine years exhibiting moderate to high heatwave events, ranging from 34 (1998) to 47 (2011). The clustering distinctly separates recent decades, particularly the years 2016, 2017, 2019, 2022, and 2023, indicating an intensified and persistent heatwave signal consistent with ongoing climate warming trends. This pattern underscores the increasing frequency and severity of heatwave events in the Anthropocene, likely driven by enhanced greenhouse gas emissions and associated changes in atmospheric circulation patterns.

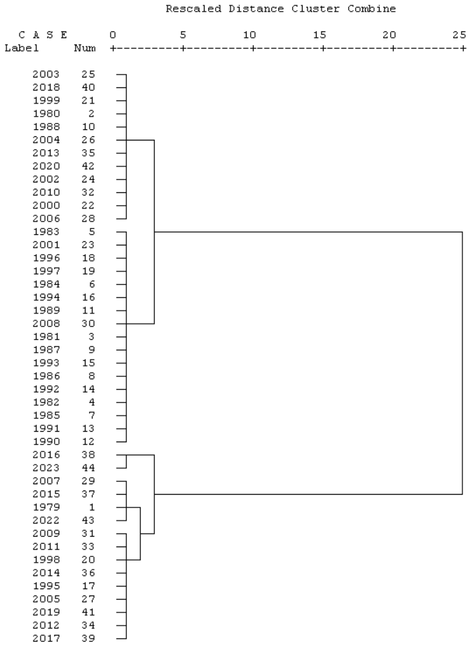

Fig. 4: Dendrogram of annual heatwave events

The hierarchical cluster analysis of heatwave-induced fatalities in India, using Ward's method with squared Euclidean distance, produced a dendrogram (Figure 5) that clearly delineates two distinct temporal clusters, indicating significant shifts in fatality patterns associated with extreme heatwave events over the past four decades. The first major cluster, comprising 40 years, is further divided into two sub-clusters. The first sub-cluster includes 29 years, predominantly from 1980 to 2010, characterized by relatively low heatwave-related fatalities, ranging from a minimum of 2 deaths in 1990 to 269 deaths in 2010. This sub-cluster represents a prolonged period of comparatively lower fatality, possibly reflecting lower heatwave intensity or limited reporting in earlier decades. The second sub-cluster, consisting of 11 years, includes isolated years between 1979 and 2019, which exhibit a moderate increase in fatalities. Fatalities in this sub-cluster range from 368 deaths in 1979 to a peak of 829 deaths in 2012, indicating a transitional phase marked by sporadic but more intense heatwave events. The second major cluster comprises four years—1998, 2003, 2013, and 2015—that experienced a notable surge in heatwave-induced fatalities, ranging from 1,433 deaths in 2013 to 2,081 deaths in 2015. This cluster represents periods of extreme fatality, corresponding with years that witnessed unprecedented heatwave intensities in India. The clear separation between these two sub-clusters at a higher rescaled distance underscores the statistical robustness of the observed temporal groupings. The clustering pattern indicates a marked shift in the severity and frequency of heatwave impacts, particularly in the post-2000 period. This trend is consistent with broader climatological evidence pointing to the increasing intensity of extreme heat events under global warming scenarios.

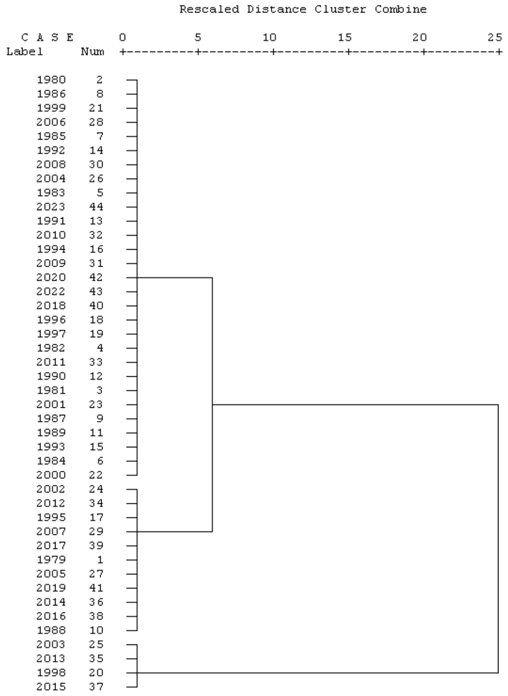

Fig. 5: Dendrogram of annual heatwave fatalities

Month-wise Distribution of Heatwave Events and Fatality

Table 6 presents the data pertaining to the month-wise distribution of heatwave events and fatalities in different states of India. From the table, it can be seen that heatwave events range from February to August. Of the different states of India, only Kerala had reported heatwave events (n = 2) in the month of February, followed by 11 states in the month of March, 21 states in April, 22 states in May, 18 states in June, and 11 states in July. The heatwave events in August were reported from Odisha (n = 1), Assam (n = 2), and Punjab (n = 5). The maximum number of heatwave events is in the order of May (437) > June (348) > April (235) > March (44) > July (23) > August (8) > February (2). From the data, it can be concluded that major heat spells in India are confined to April, May, and June, which contribute to about 93% (n = 1020) heatwave events. The total number of heatwave events in India for the study period was 1096, with 17,745 fatalities.

The maximum heatwave events in the month of March (n = 10) were recorded in Maharashtra, followed by Odisha (n = 9) and Kerala (n = 8). In the month of April, it was found to be Odisha (n = 63), Maharashtra (n = 43), West Bengal (n = 30), and Andhra Pradesh (n = 21). For May, Odisha again had the highest number of heatwave events (n = 83), followed by Maharashtra (n = 71), Andhra Pradesh (including Telangana) (n = 55), and Rajasthan (n = 45). The observation for June revealed that again Odisha had maximum heatwave events (n = 50), followed by Rajasthan (n = 42), Bihar (n = 38), Maharashtra (n = 34), and Andhra Pradesh (including Telangana) (n = 25). From these observations, it can be concluded that Odisha topped the heatwave events in India with consecutively maximum heatwave spell events in April (63), May (83), and June (50). A total of 196 heatwave events were recorded during this period in Odisha, which is ~18% of the total heatwave events of India during the study duration in consideration. The Maharashtra state had highest (n = 10) heatwave events in March and the second highest number of heatwave events in April (n = 43) and May (n = 71), and fourth in June (n = 34). The total number of heatwave events during the summer months is in the order of Odisha (208) > Maharashtra (158) > Andhra Pradesh (including Telangana) (108) > Rajasthan (105) > West Bengal (88). In the Disastrous Weather Events reports, it is reported that two school teachers, while working as a polling officer on election duty, died on 28 April 2019 in Jaipur, Rajasthan, whereas, in the Mokameh-Barauni industrial belt, 25 persons died on 6 June 1983, and on 12 June 1986, 18 persons again died in the same area.

Table 6: Month-wise distribution of heatwave events and fatality

State	February	March	April	May	June	July	August	Total number of heatwaves events	Fatality
Andhra Pradesh	Nil	6	21	55	25	1	Nil	108	8329
Arunachal Pradesh	Nil	Nil	Nil	1	Nil	Nil	Nil	1	Nil
Assam	Nil	Nil	1	3	1	1	2	8	36
Bihar	Nil	Nil	2	14	38	2	Nil	56	1746
Chandigarh	Nil	Nil	Nil	6	5	Nil	Nil	11	7
Chhattisgarh	Nil	Nil	4	9	4	Nil	Nil	17	35
Delhi	Nil	Nil	1	2	6	Nil	Nil	9	61
Goa	Nil	1	Nil	Nil	Nil	Nil	Nil	1	Nil
Gujarat	Nil	5	6	13	2	Nil	Nil	26	184
Haryana	Nil	Nil	2	9	20	4	Nil	35	124
Himachal Pradesh	Nil	1	Nil	1	3	1	Nil	6	24

Jammu and Kashmir	Nil	Nil	1	1	Nil	Nil	Nil	2	Nil
Jharkhand	Nil	1	11	9	24	Nil	Nil	45	287
Karnataka	Nil	1	4	2	Nil	Nil	Nil	7	10
Kerala	2	8	11	2	Nil	Nil	Nil	23	41
Madhya Pradesh	Nil	1	4	15	18	1	Nil	39	166
Maharashtra	Nil	10	43	71	34	Nil	Nil	158	643
Meghalaya	Nil	Nil	1	Nil	Nil	Nil	Nil	1	Nil
Odisha	Nil	9	63	83	50	2	1	208	1386
Punjab	Nil	Nil	6	25	23	3	5	62	280
Rajasthan	Nil	1	14	45	42	3	Nil	105	2063
Tamil Nadu	Nil	Nil	2	8	3	Nil	Nil	13	20
Uttar Pradesh	Nil	Nil	6	24	33	3	Nil	66	1795
Uttarakhand	Nil	Nil	1	Nil	Nil	Nil	Nil	1	Nil
West Bengal	Nil	Nil	30	39	17	2	Nil	88	508
Total	2	44	235	437	348	23	8	1096	17745

Ill/Sick/Injured

In addition to the fatality due to heatwave events, a few residents from various parts of India have reported ill/sick/injured due to it. Table 7 presents the data about the same. From the table, it can be seen that 17 such events from nine states resulted in 306 persons getting ill/sick/injured due to heatwave events. Of the 17 such events, seven (41%) were in 2019 alone and five (29%) in 2016. Of the nine states which had witnessed this health condition, Kerala had the maximum (n = 12, 57%) such events followed by West Bengal (n = 2, 10%), and Odisha, Punjab, Rajasthan, Uttar Pradesh, Bihar, Madhya Pradesh, and Jharkhand states each with one such incident. The month of April had reported maximum (n = 8, 47%) such events, followed by March (n = 5, 29%) and May (n = 3, 18%). On 1 April 2019, a maximum of 61 persons were reported injured from Kerala, followed by 51 in Midinapore (West Bengal) on 7 June 1986. Of the 306 people who were ill/sick/injured due to heatwave events, 231 (75%) were from Kerala alone.

Table 7: Residents' ill/sick/injured due to heatwave events

Date(s)	Place(s) (State)	Particular
1986, 7 June	Midinapore (West Bengal)	Fifty-one felt ill
1987, 30 May	Cuttack (Odisha)	Four people felt unconscious
1997, 15 May	Malda (West Bengal)	Ten felt sick
2004, 3rd and 4th week May	(Punjab, Rajasthan, Uttar Pradesh, Bihar, Madhya Pradesh)	Nine reported sick
2016, 5 March	Palakkad (Kerala)	Three persons were injured in Alathur
2016, 19-20 April	Alappuza, Ernakulam, Kottayam, Palakkad, Pathanamthitta, Thrissur (Kerala)	Nine people suffered burns
2016, 21-22 April	Ernakulam, Kasaragod, Kottayam, Malappuram, Palakkad, Pathanamthitta, Thrissur (Kerala)	Nine people suffered burns
2016, 27 April	Ernakulam, Pathanamthitta, Thiruvanthapuram (Kerala)	Five people suffered burns
2016, 28 April	The entire Kerala state	Sixteen people suffered burns
2017, 11 April	Ranchi (Jharkhand)	One person injured
2019, 22 March	Ernakulam, Thiruvantapuram (Kerala)	One person injured
2019, 26 March	Ernakulam (Kerala)	Two persons injured
2019, 30 March	Thrissur, Thiruvantapuram (Kerala)	Five persons injured

2019, 31 March	Alappuzha, Ernakulam, Kasaragod, Kollam, Kottayam, Kozhikode, Palakkad, Thiruvantapuram (Kerala)	Thirty seven persons injured
2019, 1 April	Alappuzha, Idukki, Kannur, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thrissur, Thiruvantapuram, Wayanad (Kerala)	Sixty one persons injured
2019, 2 April	Alappuzha, Ernakulam, Kannur, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thrissur, Thiruvantapuram (Kerala)	Forty seven persons injured
2019, 4 April	Alappuzha, Ernakulam, Kannur, Kasargode, Kollam, Kozhikode, Palakkad, Wayanad (Kerala)	Thirty six persons injured

Hospitalized

Hospitalization due to heatwave events is recorded in the annual Disasters Weather Events in India reports and is presented in Table 8. From the table, it can be seen that 14 such events leading to > 532 hospitalizations from six states have been reported. The maximum number of hospitalization events was reported from Maharashtra (n = 5, 36%), followed by Odisha (n = 3, 21%), and Uttar Pradesh and Bihar state each with two incidents, and one each in Madhya Pradesh and West Bengal. The hospitalization events in different months due to heatwaves are in the order of May (7) > June (5) > April (2). The maximum (n = 214) residents hospitalized due to heatwave events was reported from Midnapore (West Bengal), the only such event from the state ever reported on 11 May 1988. In Bihar on 6 June 1985, 150 people were hospitalized due to an attack of hyperthermia. From Odisha, 53 people were hospitalized, followed by 41 in Uttar Pradesh, and >34 in Maharashtra. The children are also vulnerable to heatwaves and reported 14 children, mostly below 12 years of age, were hospitalized from Nagpur (Maharashtra) in the 1st week of June 1979.

Table 8: Hospitalization due to heatwave events

Date	Place(s) (State)	Particular
1979, 1st week of June	Nagpur (Maharashtra)	Fourteen children, mostly below 12 years
1981, 3 June	Bundelkhand region (Uttar Pradesh)	Thirty hospitalised due to sunstroke in Jhansi
1982, 27-30 May	Hamirpur and Banda (Uttar Pradesh)	Eleven hospitalised
1984, 24 May	Balaghat (Madhya Pradesh)	Several admitted to the hospital in the Balaghat district
1985, 6 June	Gaya, Hazirabag, Nalanda, Vaishali (Bihar)	One hundred and fifty people were admitted to the hospital due to an attack of hyperthermia
1988, 11 May	Midnapore (West Bengal)	Two hundred and fourteen admitted in hospital under the Jhargam police station
1988, 31 May	Pune (Maharashtra)	Nine admitted to the hospital due to sunstroke
1989, 15 May	Bolngir (Odisha)	One hospitalised
1991, 4th week May	Chandrapur and Nagpur (Maharashtra)	Six admitted to the hospital due to sunstroke
1995, 7 June	Muzzaffarpur (Bihar)	Forty persons were hospitalised at Hajipur
1996, 29 May	Koraput (Odisha)	Two are hospitalised in Jeypore
1998, 9 June	Khurda (Odisha)	Fifty persons hospitalised
1999, 26-30 April	Vidarbha region (Maharashtra)	Five are hospitalised in Nagpur city
2001, 24 April	Jalgaon (Maharashtra)	Many persons hospitalised in Dharangaon

Child Fatality

The heatwave events have a pronounced effect on the health of the individuals. Of these individuals, children, particularly from rural and socio–economically weaker sections, may be at the receiving end. The child fatality due to heatwave events in India during the study period is presented in Table 9. From the table, it can be seen that 18 child fatality events have been reported from nine states, with the maximum from Maharashtra and Punjab (n = 5 each, 28%), followed by West Bengal (n = 2, 11%), and Bihar, Karnataka, Rajasthan, Haryana, Madhya Pradesh, and Chandigarh, each with one (6%) event. Of the 27 child fatalities reported due to heatwave/sun–stroke in India, three (11%) were infants, six (22%) were girls, two (7%) were boys, and 16 (59%) gender was not mentioned. From this observation, it can be inferred that the vulnerability level for fatality due to heatwave events is in the order of girls > infants > boys. Of the different months in which these child fatality events were recorded, a maximum of 11 (61%) were observed in May, followed by June (n = 4, 22%), and April (n = 3, 17%). Thus, it can be arrived at May month is particularly vulnerable to girls and infant fatalities due to heatwave events in India. Thus, suitable measures from local government agencies need to be taken to reduce the vulnerability and fatality of children to heatwaves.

Table 9: Child fatalities due to heatwave events

Date(s)	Place(s) (State)	Particular
1980, 14-17 May	Nagpur (Maharashtra)	Two infants and a nine-year-old died of sunstroke
1983, 23 June	(Punjab)	One six months old baby died in Phagwara
1985, 30 May	Ferozepur (Punjab)	Two children died at Baghpurana
1988, 16 May	Gaya (Bihar)	Three children died at Vazirganj
1988, 31 May	Pune (Maharashtra)	A three-year-old girl died
1989, 16 May	Bangalore (Karnataka)	An eight-year-old girl died
1994, 6 May	Nadia and North 24 Parghanas (West Bengal)	One schoolgirl died
1995, 28 April	Bardhaman (West Bengal)	A seven-year-old boy died at Bagar village
1995, 30 May	Yavatmal (Maharashtra)	One child died
2002, 9 May	Sangrur (Punjab)	Two children in a family died in Maler Kotala
2002, 8 June	Dholpur (Rajasthan)	Three girls died
2006, 12-14 May	Bhatinda (Punjab)	Two children died
2006, 3 June	Ferozepur (Punjab)	One child died
2006, 11-13 June	Chandigarh (Union Territory) and Pachkula (Haryana)	One child died
2009, 29-30 April	Indore (Madhya Pradesh)	A child died
2009, 21 May	Chandigarh (Union Territory)	One student died
2011, 7 April	Jalgaon (Maharashtra)	One child died due to sunstroke
2018, 7 May	Solapur (Maharashtra)	One 16-year-old boy died in Pandharpur

Animal's Death

The heatwave events have an adverse impact not only on human beings but also on animals. The animal's death due to heatwave events in various parts of India is presented in Table 10. From the table, it can be seen that 22 heatwave events induced animal fatalities are reported in India during the study period. The most vulnerable animal is cattle with a fatality of 5054, followed by peacocks (n = 238) and monkeys (n = 20). Several birds perished due to six heatwave events. The other animals that died due to heatwave events include fish, tiger cubs (n = 2), grey horns (n = 60), deer (n = 6), and buffalo (n = 1). The maximum (n = 3000) cattle heads that perished were reported from Hazaribagh (erstwhile Bihar, now Jharkhand) on 7 June 1983. Three incidents where peacock (*Pavo cristatus*) deaths due to heatwave events were reported (Two in Rajasthan and one in Madhya Pradesh). The peacock is the national bird of India and is found to be vulnerable to heatwave events. One of the significant events of the heatwave was reported from Gulbarga (Karnataka) on 7 May 2000, where millions of fish died on the banks of Appanna Kare, affecting about 2500 persons dependent on fishing affected with an economic loss of Rupees 20 lakh (US$45830 in 2000).

Table 10: Animal deaths due to heatwave events

Date(s)	Place(s) (State)	Particular
1981, 14 April	Khandwa (Madhya Pradesh)	One animal and some birds died
1983, 2-7 June	Chitrakoot Dham (Uttar Pradesh)	Twenty monkeys died
1983, 7 June	Hazaribagh (Jharkhand)	Three thousand cattle heads perished
1985, 6 June	(Bihar)	Forty-two cattle heads perished
1988, 31 May	Pune (Maharashtra)	A large number of birds perished
1992, 25-27 May	(Rajasthan)	Thousands of cattle heads/birds perished
1995, 3 June	Vidisha (Madhya Pradesh)	A large number of birds perished
1995, 3 June	Dhanbad and Nalanda (Bihar)	Twelve cattle heads perished
2000, 7 May	Gulbarga (Karnataka)	Lakhs of fish died on the banks of Appanna Kare. About 2500 persons are dependent on the fishing industry and the estimated loss of Rupees 20 lakh
2000, 4th week of May	Churu (Rajasthan)	One hundred twenty peacocks died
2001, 1st and 2nd week of May	Jaipur city (Rajasthan)	Eighteen peacocks died near the Heerapura power grid substation
2001, 1st and 2nd week of May	Kota (Rajasthan)	Two tiger cubs died in the zoo
2002, 1-9 May	Shrigonda (Maharashtra)	Sixty grey horns perished
2002, 26 May	Kendrapara (Odisha) Cuttack (Odisha)	Six deer died in Bhitarkanika National Park Many animals feel sick
2003, June	(Odisha)	Many birds perished
2004, 19 April	Baripada, Mayurbhanj (Odisha)	Several birds perished
2007, 14-16 May	Morena (Madhya Pradesh)	About 100 peacocks perished
2016, 21-22 April	(Kerala)	Four cows perished
2016, 27 April	(Kerala)	Two animals perished
2019, 26 March	Wayanad district (Kerala)	Three livestock perished
2019, 13 June	Ranchi (Jharkhand)	A buffalo perished

Crop Loss/Damage

The heatwave events have a pronounced impact on agriculture too. The six incidents of crop loss due to heatwaves were reported (Table 11) during the study period. Of the six crop loss incidents recorded, three (50%) were recorded in 2009 and two (33.33%) in 2016. Of these six events, three (50%) were from Punjab alone, and of these three, two (67%) were from Bathinda district, where cotton and wheat crops were damaged. Punjab has also reported crop damage on 57,000 hectares due to heatwave events. This is a matter of concern as Punjab serves as the 'Wheat Bowl of India'. If such heatwave events occur further, it will result in a more pronounced adverse impact on crops. In Uttarakhand state, which has reported only one heatwave event (29-30 April 2009) with no fatality, however resulted in a major forest fire in which a jungle of 2426 hectares was destroyed. The Kerala state had also witnessed crop damage/loss due to heatwave events. Kerala is known as the 'Spice Garden of India' and the 'Land of Coconuts' and is also the home of coffee and banana. The heatwave events will not only cause crop loss/damage, but will also result in economic loss and lead to a vicious cycle of crop loss, leading to farmers' deaths. The crop loss/damage due to heatwave events was reported in cotton, wheat, banana, black pepper, and vegetables.

Table 11: Crop loss/damage due to heatwave events

Date(s)	Place(s) (State)	Particular
2002, 12-13 May	Bhatinda (Punjab)	Damage to the cotton crop
2009, 29-30 April	Bhatinda (Punjab)	Damage to wheat crops at many places
2009, 29-30 April	Garhwal and Kumaon (Uttarakhand)	Forest fire reported A jungle of 2426 hectares was destroyed
2009, 25-30 June	(Punjab)	Crops on 57,000 hectares were damaged
2016, 26 April	(Kerala)	1038 hectares of agricultural crops worth Rupees 16 crores were damaged
2016, 28 April	The entire Kerala state	Standing crops viz. Banana, Papper & vegetables around 134.84 hectares of land were whitened due to a prolonged dry spell. Total loss worth 35 crores reported. Rupees 2.83 crore from Papper cultivation farmers, while Rs. 2.13 crore on 38 hectares of land from 404 Banana cultivation farmers. Damage to more than 97000 Banana plants reported.

Drinking Water Shortage

Of the different impacts of heatwave events, drinking water shortage is one of them. The acute shortage of drinking water due to heatwave events was reported five times during the study period from Rajasthan (n = 2), West Bengal, Chhattisgarh, and Odisha states (Table 12). Of these five incidents, three (60%) were reported in May and two (40%) in June. In Rajasthan, acute drinking water shortage was reported twice in June 1992. As the southwest monsoon reaches Rajasthan in July, such conditions may have resulted in. As 10,000 tube wells were dried up in various parts of Odisha in May 2000, to meet the water demand, it was brought by trains and tankers and supplied to the affected areas. Of the five such incidents ever reported, two (40%) were reported in 1992 and in the month of June from Rajasthan state.

Table 12: Drinking water shortage due to heatwave events

Date(s)	Place(s) (State)	Particular
1978, 20-26 May	Korba and Bilaspur (Chhattisgarh)	Acute shortage of drinking water
1988, 7-12 May	Bankura (West Bengal)	Acute shortage of drinking water
1992, 4 June	Rajasthan (Entire state)	Acute shortage of drinking water
1992, 12-22 June	Rajasthan (Entire state)	Acute shortage of drinking water
2000, 1-2 May	Bolangir, Jharsuguda, and Kandhamal (Odisha)	10,000 tube wells dried up. Water was brought by trains and tankers and supplied to the affected area

The acute drinking water shortage in summer, especially where groundwater is used as a source of drinking water, is a regular phenomenon in various parts of India from February onwards. To meet the drinking water demand of the residents, the same was provided by tankers by local government agencies. This supply of drinking water continues from February to June/July–till the onset of the southwest monsoon. In the year 2016, in the parched Latur city (in Maharashtra state) and surroundings, drinking water continued to be supplied through a special train operated by Indian Railways–*Jaldoot* (water train) carrying fresh drinking water over a distance of 343 kilometres from

Miraj in Osmanabad to Latur. On the inception of this activity on April 11, 2016, 5 lakh litres (0.5 million litres) of drinking water through 10 tanker wagons were supplied. Later, the number of wagons was increased to 50, and by 30 July 2016, about 24 crore litres (240 million litres) of drinking water was supplied by completing 100th trips. Each refill of '*Jaldoot*' took about 12-14 hours before being dispatched to the destination. The Maharashtra state government provided police security to water tankers and reservoirs and imposed prohibitory orders at water distribution points (Indo-Asian News Service, 2016).

El Nino and Heatwave Fatalities and Events

Table 13 summarizes the heatwave-induced fatalities for selected El Nino years, categorized by strength (Very Strong – VS and Strong – S), and includes corresponding data for the year preceding the El Nino event, the El Nino year itself, and the succeeding year. Values in parentheses represent secondary indicators, i.e., heatwave events. Very Strong (VS) El Nino years (1982, 1997, and 2015) display a variable but discernible pattern in their temporal profiles. For instance, during the 1982 El Nino event, there was a marked drop in heatwave-induced fatalities (heatwave events) from 75 (10) in the preceding year to 16 (5) during the El Nino year, followed by a sharp increase to 187 (7) in the succeeding year. Similarly, the 1997 event showed relatively low values before and during the El Nino year—20 (9) and 21 (9), respectively—followed by a significant surge to 1712 (34) in the subsequent year. In contrast, the 2015 event exhibited an anomalously high value during the El Nino year—2081 (29), which was preceded by 548 (35) and followed by a sharp decrease to 526 (58) in the succeeding year. These results suggest a high interannual variability in the impact of Very Strong El Nino events, with some instances associated with major post El Nino increases in the observed measure, while others peak during the event year itself.

For Strong (S) El Nino events (1987, 1991, and 2023), a generally more consistent pattern is observed. The 1987 event exhibited moderate values before the El Nino (156 (5)), with a decrease during the event (87 (6)), followed by a notable increase to 635 (15) in the succeeding year. The 1991 El Nino showed a minimal value before the event (2 (2)), a considerable rise during the El Nino (252 (4)), and a return to moderate levels in the succeeding year (114 (5)). Data for the 2023 El Nino, which was also classified as Strong, show an increase from 30 (27) in the preceding year to 181 (53) during the event. Data for the succeeding year (2024) are currently unavailable.

Overall, the results indicate that both Strong and Very Strong El Nino events are often associated with significant variability across the three-year window. In several instances—especially for VS events—a pronounced increase in the measured variable is seen in the year following the El Nino, suggesting potential delayed effects. Strong El Nino events appear to produce less extreme variations, though consistent fluctuations are still evident. A Friedman test revealed a statistically significant difference across the timepoints ($\chi^2(2) = 9.33$, $p = 0.0094$), indicating that the occurrence of an El Nino event is associated with measurable changes in the heatwave-induced fatalities (heatwave events). A Wilcoxon signed-rank test was conducted to explore pairwise differences between preceding *vs* during El Nino revealed no significant difference ($p = 0.31$), during *vs* succeeding year, with a significant increase ($p = 0.031$), and preceding *vs* succeeding year, again with a significant increase ($p = 0.016$). These results suggest that the largest and most consistent effect occurs in the year following an El Nino, particularly for Very Strong events, where observed values frequently peak post-event (e.g., 1712 in 1998 and 187 in 1983). While changes during the El Nino year are evident, they are more variable in direction and magnitude.

Table 13: Influence of El Nino on heatwave-induced fatalities and events

El-Nino Year	Year preceding El-Nino	During El-Nino year	Succeeding year
1982 (VS)	75 (10)	16 (5)	187 (7)
1997 (VS)	20 (9)	21 (9)	1712 (34)
2015 (VS)	548 (35)	2081 (29)	526 (58)
1987 (S)	156 (5)	87 (6)	635 (15)
1991 (S)	2 (2)	252 (4)	114 (5)
2023 (S)	30 (27)	181 (53)	No data

VS – Very strong, S – Strong. Values in parentheses indicate heatwave events

La Nina and Heatwave Fatalities and Events

Table 14 summarizes the heatwave-induced fatalities (heatwave events) across eight La Nina events from 1988 to 2021, classified by strength as Strong (S) or Moderate (M). For each event, data are presented for the year preceding the La Nina, the La Nina year itself, and the succeeding year. Across the dataset, a range of dynamic temporal patterns is evident. For example, the 1988 La Nina year showed a dramatic increase in heatwave-induced fatalities (heatwave events) from 87 (6) in the preceding year to 635 (15) during the La Nina, followed by a significant drop to 44 (10) in the succeeding year. A similar spike is observed in 1998, where values increased sharply during the La Nina (1712 (34)) before decreasing to 132 (14) in the succeeding year.

However, not all events followed this trend, with several Moderate La Nina events (e.g., 2020 and 2021) showing overall lower and more stable values or incomplete data. The Friedman test revealed a statistically significant difference (Friedman $\chi^2(2) = 8.60$, $p = 0.0135$) in observed values across the three periods (Preceding, During, and Succeeding years). This result suggests that La Nina events are associated with statistically significant fluctuations in the measured variable across the observed timeframe. A Wilcoxon signed-rank test was used for post-hoc pairwise comparisons, which revealed preceding *vs* during La Nina with $p = 0.031$, indicating a significant increase during La Nina whereas during *vs* succeeding with $p = 0.063$, indicating a marginal decrease (not statistically significant), and preceding *vs* succeeding with $p = 0.094$, indicating not significant difference. The analysis confirms that the most significant change occurs between the year before La Nina and the La Nina year itself, indicating that the event onset often triggers a sharp increase in the heatwave-induced fatalities (heatwave events). Stratification by La Nina strength suggests that Strong La Nina events are associated with higher variability and more pronounced peaks during the event year, whereas Moderate events tend to show more stable or reduced values.

Table 14: Influence of La Nino on heatwave-induced fatalities and events

La-Nina Year	Year preceding La-Nina	During La-Nina year	Succeeding year
1988 (S)	87 (6)	635 (15)	44 (10)
1998 (S)	21 (9)	1712 (34)	132 (14)
1999 (S)	1712 (34)	132 (14)	55 (21)
2007 (S)	135 (21)	419 (29)	111 (10)
2010 (S)	216 (43)	269 (23)	12 (47)
2011 (M)	269 (23)	12 (47)	829 (39)
2020 (M)	504 (41)	27 (18)	Nil
2021 (M)	27 (18)	Nil	30 (27)

S – Strong, M – Moderate. Values in parentheses indicate heatwave events

South–west Monsoon and Heatwave Events

Table 15 represents the dataset for monthly heatwave events recorded from February to August across India, in conjunction with the documented onset dates of the South-West monsoon (SWM). Minimal or nil heatwave events were reported across nearly all states from February through April, with only a few states (e.g., Kerala, Andhra Pradesh, Gujarat, Maharashtra) showing early heatwave events. A marked increase in it was observed beginning in May, particularly in southern and eastern states. Notably, Odisha recorded a sharp rise in it from 9 (March) to 83 (May), sustaining high values into June (50). Maharashtra showed consistent pre-monsoon increases in heatwave events, peaking at 71 in May. West Bengal and Bihar showed significant increases in it in May and June. Rajasthan, with monsoon arrival on 30 June–5 July, showed a rise in heatwave events starting in April (14), peaking at 45 in May. In contrast, northern states such as Chandigarh, Delhi, Punjab, and Haryana exhibited little to no activity until June, with small peaks observed in late June and early July. Those states which receive SWM up to 15 June had very few events of heatwaves in July (four states with six events), and only Odisha state reported one heatwave event in August. In case of states where SWM arrives after 15 June, heatwaves range from April to August, with seven states reporting 17 heatwave events in July and seven heatwave events from two states in August. Thus, it can be concluded that SWM has a direct impact on the heatwave distribution in India. Those states which have SWM onset date up to 15 June, heatwave events range from February to June, and those where monsoon onset date is after 15 June, the heatwave events range from April to August. In the case of states where SWM arrives before 10 June (n = 15), heatwave events are confined to June, except for three states (20%) that had reported heatwaves in July also. Those states where SWM arrives after 15 June have experienced heatwave events till July. Of the 15 states which has SWM arrival dates of 15 June and later, 53% (n = 8) have reported heatwave events till July.

Table 15: South-west monsoon and heatwave events

State	Feb.	March	April	May	June	July	Aug.	SWM arrival date(s)
Rajasthan	Nil	1	14	45	42	3	Nil	30 June-5 July
Chandigarh	Nil	Nil	Nil	6	5	Nil	Nil	30 June
Haryana	Nil	Nil	2	9	20	4	Nil	30 June
Punjab	Nil	Nil	6	25	23	3	5	30 June
Delhi	Nil	Nil	1	2	6	Nil	Nil	25-30 June
Himachal Pradesh	Nil	1	Nil	1	3	1	Nil	25 June
Jammu and Kashmir	Nil	Nil	1	1	Nil	Nil	Nil	25 June
Uttarakhand	Nil	Nil	1	Nil	Nil	Nil	Nil	20-25 June
Uttar Pradesh	Nil	Nil	6	24	33	3	Nil	20-25 June
Gujarat	Nil	5	6	13	2	Nil	Nil	20-25 June
Madhya Pradesh	Nil	1	4	15	18	1	Nil	15-20 June
Odisha	Nil	9	63	83	50	2	1	15 June
Bihar	Nil	Nil	2	14	38	2	Nil	15 June
Jharkhand	Nil	1	11	9	24	Nil	Nil	15 June
Chhattisgarh	Nil	Nil	4	9	4	Nil	Nil	15 June
Maharashtra	Nil	10	43	71	34	Nil	Nil	10-15 June
West Bengal	Nil	Nil	30	39	17	2	Nil	10 June
Sikkim	Nil	Nil	Nil	Nil	Nil	Nil	Nil	10 June
Andhra Pradesh	Nil	6	21	55	25	1	Nil	5-10 June
Arunachal Pradesh	Nil	Nil	Nil	1	Nil	Nil	Nil	5 June
Assam	Nil	Nil	1	3	1	1	2	5 June
Nagaland	Nil	Nil	Nil	Nil	Nil	Nil	Nil	5 June
Meghalaya	Nil	Nil	1	Nil	Nil	Nil	Nil	5 June

Manipur	Nil	Nil	Nil	Nil	Nil	Nil	Nil	5 June
Tripura	Nil	Nil	Nil	Nil	Nil	Nil	Nil	5 June
Mizoram	Nil	Nil	Nil	Nil	Nil	Nil	Nil	5 June
Goa	Nil	1	Nil	Nil	Nil	Nil	Nil	5 June
Karnataka	Nil	1	4	2	Nil	Nil	Nil	5 June
Tamil Nadu	Nil	Nil	2	8	3	Nil	Nil	1 June
Kerala	2	8	11	2	Nil	Nil	Nil	1 June

Time Series Analysis of Heatwaves Events and Fatalities

The time series analysis (Futuristic analysis) was conducted to examine yearly heatwave events and fatalities associated with them in India from 1979 to 2023, with an objective of modeling and forecasting future heatwave events and fatalities patterns up to 2030. It was carried out by using the Expert modeler method and all model types by using SPSS software. To stabilize the variance and achieve stationarity, the series was first log-transformed and then used.

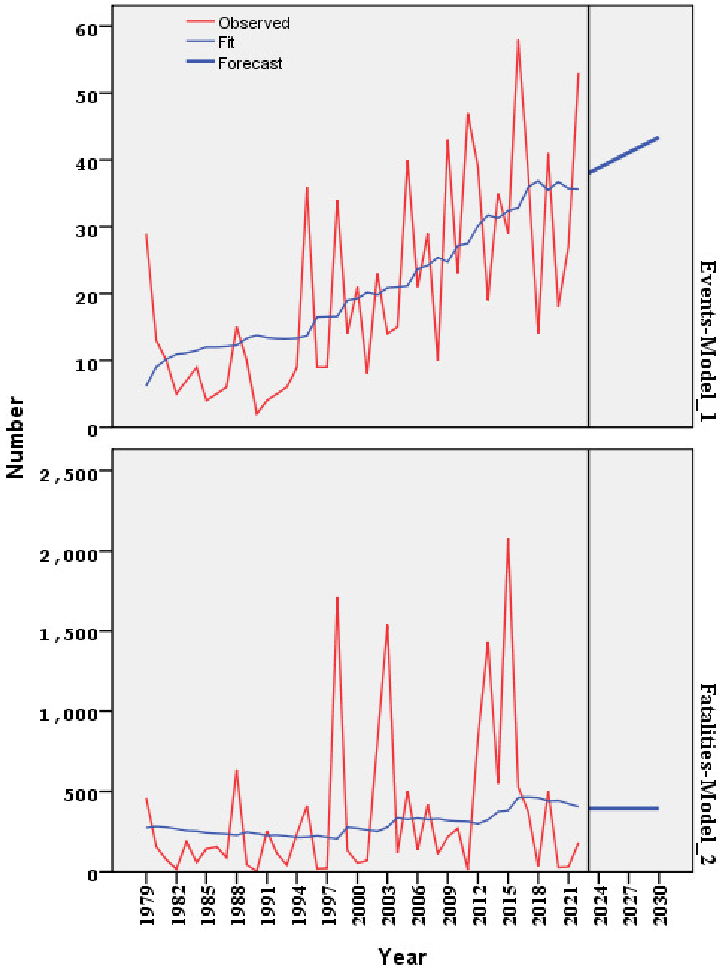

Fig. 6: Time series analysis of heatwave events and fatalities in India

Figure 6 presents the time series analysis of heatwave events (top panel) and associated fatalities (bottom panel) in India from 1979 to 2023, along with forecasts extending to 2030. The observed data is shown in red, while the fitted and forecasted values are represented in blue. The vertical black line marks the boundary between the historical and forecast periods. The frequency of heatwave events shows a clear upward trend over the historical period. From relatively low and erratic counts in the 1980s and early 1990s, the number of events began to increase more consistently from the late 1990s onwards, reaching peaks above 50 in some years after 2010. The fitted model closely tracks the long-term trend despite interannual variability, and the forecasted values suggest a continued increase in the frequency of heatwaves. The model forecasts the number of annual events to rise from 38 in 2024 to 43 by 2030 (Upper confidence level 68 and lower confidence level 19). The upward trajectory suggests that India may continue to face increasing heatwave exposure under prevailing climatic trends.

In contrast to the steadily increasing trend in events, the time series of fatalities exhibits high variability with numerous extreme spikes, especially in the 1990s and early 2000s, where annual fatalities exceeded 1,000–2,000 in several years. However, after 2015, a decline in both the frequency and intensity of fatality spikes is observed. The model forecasts a flat trajectory of approximately 395 fatalities annually from 2024 to 2030 (Upper confidence level 1386 and lower confidence level -596). The flat forecast and wide confidence intervals suggest significant uncertainty, likely due to external factors influencing heatwave fatality (e.g., adaptive measures, early warning systems, urban planning, and public health responses).

Events-Model demonstrates strong model performance, with high stationary R-squared ($R^2 = 0.846$) and a non-significant Ljung-Box test, indicating well-behaved residuals. Fatalities-Model, although statistically acceptable in terms of residual autocorrelation, shows a negative R-squared ($R^2 = -0.020$), suggesting a poor fit to the observed data. This reflects the inherent volatility in heatwave fatalities, likely driven by non-climatic factors not captured in the time series.

The time series analysis and forecasts of heatwave events and associated fatalities in India from 1979 to 2030 provide important insights into the evolving nature of extreme heat risk in the country. The findings underscore a clear divergence between the increasing frequency of heatwave events and the nonlinear, highly variable trend in fatalities, with projections suggesting a decoupling between climate hazards and fatality outcomes.

The results from Events-Model indicate a robust and statistically significant upward trend in the frequency of heatwave events over the past four decades. This finding aligns with broader regional and global patterns linking climate change to the increasing occurrence of extreme temperature events, particularly in South Asia, where warming trends have been exacerbated by both natural variability and anthropogenic forcing (IPCC, 2021). The projected rise to 43 events by 2030 underscores a growing burden of heat stress, with likely implications for public health, agriculture, and energy systems. This pattern also aligns with the El Nino-Southern Oscillation, which can exacerbate summer heat extremes in India. As heatwaves become more frequent and prolonged, their impacts are expected to intensify unless substantial adaptation measures are implemented.

In contrast, Fatalities-Model presents a flat forecast and a poorly fitting model due to the erratic and episodic nature of past fatality data. High peaks in deaths during the 1990s and early 2000s likely reflect periods of inadequate preparedness, poor public health infrastructure, and limited early warning dissemination.

According to Chaudhury *et al.* (2000), the heatwaves typically originate in northwest India and spread to nearby regions of the nation from there. Heatwaves can also occasionally form on-site. Severe heatwaves are caused by favourable conditions, such as a warm, dry air area and a suitable flow pattern that transports hot air over the area; the upper air over the area should have little to no moisture, the sky should be nearly cloudless to allow for maximum insolation over the region, the lapse rate should approach dry adiabatic, and there should be a large amplitude anticyclonic flow or thickness values in all layers that are significantly above normal. The loss of human life in a region due to heatwaves does not only depend on the number of heatwave events but also on the socio-economic conditions of the residents of the area.

In recent years, heatwaves have emerged as a significant climate-related hazard in India, contributing to increased fatalities, public health crises, and disruptions to infrastructure. Notably, the intensification and frequency of such extreme temperature events are not confined to India alone. Similar occurrences have been documented across various global regions, including Europe, North America, and parts of Asia. This section examines recent international heatwave events, thereby demonstrating that the rising prevalence of extreme heat is a global phenomenon with far-reaching implications for environmental resilience and public policy.

A weather station located in the Norwegian sector of the Arctic Circle noted temperatures exceeding 30°C on 13 separate days in July 2025. In Sweden, several northern weather stations reported prolonged heatwaves, with a station in Haparanda registering temperatures of 25°C or higher for 14 consecutive days. In Jokkmokk, Lappland, the heatwave persisted for 15 days (Guardian, 2025b). Finland experienced a continuous three-week period in 2025 where temperatures surpassed 30°C, marking the longest duration in records dating back to 1961 and 50% longer than the previous record. An ice rink in northern Finland opened its doors for those seeking relief from the heat after the local hospital's emergency room was overrun with patients (Guardian, 2025b). A historic and prolonged heatwave in Finland has led to distress and even fatalities among reindeer, as temperatures remained above 25°C. Reports indicate that reindeer are particularly vulnerable to wolf predation during heat stress. Additionally, the high temperatures disrupt the reindeer’s thermoregulation, leading to overheating. Observations revealed that the animals sought shade instead of roaming through forests in the summer (Straits Times, 2025). The UK, Norway, and Switzerland are predicted to experience the greatest relative increase in uncomfortably hot days as global temperatures rise, with current infrastructure ill-equipped to handle such changes (Guardian, 2025b).

In Nordic nations, excessive heat and overcrowding in hospitals have led to the cancellation of scheduled surgeries. At least 60 individuals have drowned due to an increase in outdoor swimming activities. Reports have surfaced of people fainting during the holiday season amidst numerous forest fires. There has been a rise in toxic algal blooms in both seas and lakes. Every country is vulnerable to climate change, as even typically cooler Scandinavian countries are currently grappling with severe heatwaves at a 1.3°C increase. If global temperature rises reach 2.6°C, heatwaves like those experienced in Scandinavia could become five times more common by 2100, which is currently the projected trajectory (Guardian, 2025a).

Madrid is currently experiencing another severe heatwave, with temperatures exceeding 40°C, and approximately 1,000 people in Spain have died from extreme heat between May and July 2025—a significant rise compared to the previous year. Several climate shelters have been established throughout the city, offering spaces for resting, working, and storing plants while residents are away (Ris, 2025). Heatwaves impact extensive regions, and post-2050, the Mediterranean is expected to see these conditions last for up to 50 days, effectively subjecting residents to prolonged summers under heatwave circumstances (Tourki, 2025).

In August 2025, the United Arab Emirates (UAE) experienced significant heat. Dubai and Abu Dhabi recorded very warm conditions, with maximum temperatures around 41°C and 42°C, while nighttime temperatures stayed above 34°C and near 33°C, respectively, leading to uncomfortable evenings. The interior regions of the UAE encountered even higher temperatures, with some locations reaching between 42°C and 47°C. The coastal cities faced increased humidity, elevating the heat index and raising the risk of heat-related health issues. The presence of blowing dust further exacerbated discomfort and health hazards (Times of India, 2025). According to EM-DAT, an extreme heatwave during the Hajj pilgrimage in Mecca, Saudi Arabia, resulted in 1,301 fatalities in June 2024, making it one of the top ten global mortalities due to various disasters that year (CRED, 2025).

South Korea witnessed its second-hottest July in 2025, marked by a record stretch of 22 "tropical nights," with temperatures exceeding 25°C, resulting in an average temperature of 27.1°C. The hottest July recorded in South Korea was in 1994, with an average temperature of 27.7°C. Emergency services in the country also reported a notable rise in calls concerning heat-related illnesses. Parts of Vietnam are enduring unprecedented heat; Hanoi recorded its first-ever day in August 2025 with temperatures above 40°C, transforming the capital into “a pan on fire” (BBC, 2025).

Japan set two new high-temperature records in 2025, with temperatures reaching 41.6°C and then 41.8°C, surpassing the previous record of 41.1°C established in 2018 and 2020. An estimated fifty-six individuals are thought to have succumbed to heatstroke in Japan from mid-June to the end of July, and heatstroke warnings were issued in 44 out of the 47 prefectures in the country (Aljazeera, 2025). Over 53,000 people have been hospitalized due to heat stroke (CNN, 2025). Last summer was among the hottest on record in Japan, matching the extreme conditions observed in 2023, and was followed by the warmest autumn since records began 126 years ago. The iconic cherry trees in Japan are blooming earlier due to the rise in temperatures, or sometimes not blooming fully because autumns and winters are not cold enough to initiate flowering. Additionally, authorities have cancelled some train services over concerns that the extreme heat may warp or damage the tracks. There are reports of water shortages in some dams and rice paddies in Japan, with farmers voicing concerns that the intense heat, coupled with insufficient rainfall, is hindering rice cultivation. The elderly population in Japan, which is the second oldest in the world after Monaco, is especially vulnerable to heatwaves (Aljazeera, 2025). The severe heat experienced in 2023 compromised the quality of rice in Japan, leading to a significant shortage the following year, a situation worsened by the government’s failure to accurately assess supply and demand, which resulted in record-high prices of this essential food item and triggered a national crisis (CNN, 2025).

In India, heatwaves from March to June 2024 accounted for 733 deaths, while Pakistan recorded 568 fatalities. Preliminary data from Phoenix (Arizona) and Las Vegas (Nevada), USA, indicate about 1,006 deaths due to heat in 2024. In Bangladesh, around 33 million children experienced the effects of extreme heat in 2024 (CRED, 2025).

Conclusion

This study relies on historical data of heatwave events and fatalities in India, which may have reporting inconsistencies, especially in earlier decades. Heatwave fatality is shaped by a multitude of interacting factors—including socio-economic status, age, occupation, housing quality, and healthcare access. The flat forecast in fatalities may not fully account for future demographic trends or intensifying heat stress due to compound hazards (e.g., drought and heatwaves). The increasing trend in heatwave events is a clear signal to policymakers and disaster managers to initiate appropriate measures to reduce vulnerability to it. The limitations of time series modeling in capturing human adaptation and nonlinear thresholds in fatality risk also need to be acknowledged.

While India is likely to face a higher frequency of heatwaves, timely adaptation measures may prevent a proportional increase in fatalities. Continued investment in climate resilience, improved data systems, and targeted interventions will be essential to manage the health burden of extreme heat in the coming decades. The recommendation to reduce vulnerability of residents to heatwaves includes: scaling up existing Heat Action Plans nationwide, especially in high-risk states and districts; integrating heat risk into urban and rural development plans, including heat-resilient housing, water supply, and green infrastructure; enhancing real-time surveillance of heat-related illnesses and fatalities to improve data quality and timely interventions; investing in forecast-based financing and anticipatory action, especially for vulnerable populations such as outdoor workers, the elderly, and children.

It is imperative to integrate traditional knowledge into climate adaptation strategies—particularly through the construction of eco-friendly housing that enhances thermal comfort throughout the year. Developing a country-specific temperature threshold formula is crucial for protecting outdoor workers, enabling timely interventions and the legal right to suspend work during extreme heat. Adapting to heatwaves requires not only behavioural changes at the individual level but also coordinated, cross-sectoral action. Strong collaboration among government agencies, institutions, and key sectors such as agriculture, tourism, health, and civil protection is essential. Furthermore, the establishment of an early warning system that communicates the expected intensity, duration, and potential impact on vulnerable populations will be critical to reducing heat-related risks and strengthening societal resilience.

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