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Original Article

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Heat-Waves as a Growing Global Health Crisis: Multi-decadal Evidence from 1936 to 2024

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Abstract

Aim: Heat-wave disasters are among the most lethal and rapidly escalating categories of natural hazards. Despite growing evidence of their increasing frequency and mortality burden, a comprehensive multi-decadal global assessment has been lacking.

Materials and Methods: Using Emergency Events Database records from 1936 to 2024, we quantified heat-wave disaster frequency, mortality, and geographic distribution. Linear regression was applied to assess temporal trends at annual and decadal scales, and the Kruskal-Wallis test with Dunn post-hoc analysis was used to compare per-event mortality across continents.

Results: A total of 344 heat-wave disasters were recorded across 75 countries, resulting in 350,425 deaths. Europe recorded the highest number of events (n=184; 53.5%) and the overwhelming majority of fatalities (320,418 deaths; 91.4%), despite comprising predominantly high-income nations—a paradox driven by aging populations, low air-conditioning penetration, and urban heat island effects. India experienced the highest event frequency (n=32), while the Russian Federation recorded the highest mean deaths per disaster (18,677.3; n=3 events). Disaster frequency increased significantly over time (β=0.170 events year $^{-}$(1); p<0.001; R(2)=0.294), as did annual mortality (β=204.1 deaths year $^{-}$(1); p<0.001). Decadal aggregation revealed even stronger relationships (R(2)=0.725 and 0.592, respectively). May through August accounted for 87.8% of events and 98.4% of global deaths.

Conclusion: Heat-wave disasters are intensifying in frequency and lethality globally. Urgent investment in early warning systems, equitable cooling infrastructure, and evidence-based climate adaptation policy is essential to reduce future heat-wave mortality.

Keywords: Heat-wave disaster, climate change, extreme temperature, vulnerability, Emergency Events Database, global disaster epidemiology

Introduction

Heat-waves-sustained periods of anomalously high temperatures relative to local climatological norms-rank among the most lethal natural hazards on Earth. Unlike floods or storms, their destruction is largely invisible: heat causes death through a cascade of physiological failures including heat stroke, cardiovascular decompensation, acute kidney injury, and respiratory compromise, disproportionately affecting the elderly, outdoor workers, and individuals with chronic disease (1,2). Globally, an estimated 489,000 heat-related deaths occurred annually between 2000 and 2019 (1-3), and this burden is accelerating. 2023 was the hottest year on record, with approximately 178,486 excess deaths attributed to heat-waves worldwide, more than half of which were directly attributable to human-induced climate change (3).

The true scale of heat-wave mortality was brought to global attention by the European summer of 2003, which caused more than 70,000 excess deaths across the continent (4) a single event that redefined heat as a major public health emergency. The 2010 Russian heat-wave caused approximately 56,000 deaths in 44 days (5), and subsequent European summers in 2022 and in 2023 resulted in an estimated 61,672 (6) and 47,690 heat-related deaths (7). These repeated catastrophes reflect a clear physical reality: the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) concluded with virtual certainty that the frequency and intensity of hot extremes have increased

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globally since the 1950s, driven primarily by anthropogenic greenhouse gas emissions, and they will continue to intensify under all future warming scenarios (8). At 2 °C of global warming, heat-mortality events that historically recurred once per century are projected to occur at least once every five years (9).

Despite this escalating burden, the global multi-decadal epidemiology of heat-wave disasters-as formally recorded events meeting standardized impact thresholds-has not been comprehensively characterized. Prior research has predominantly focused on temperature-mortality associations in specific cities, on excess mortality during individual events, or on modeled projections of future heat burden. Critically, no study has leveraged the Emergency Events Database (EM-DAT), the world's most comprehensive standardized disaster registry (10), to analyze the full historical record of heat-wave disasters across all continents and income groups over a multi-decadal horizon. As a result, the long-term evolution of heat-wave disaster frequency, mortality burden, and geographic vulnerability patterns remains systematically uncharacterized (11).

This study addresses these critical gaps by analyzing all heat-wave disasters recorded in EM-DAT from 1936 to 2024-the most temporally comprehensive global assessment of its kind. We quantify temporal trends in disaster frequency and mortality at annual and decadal scales, describe the geographic distribution of events and deaths across continents and countries, and evaluate vulnerability using deaths per disaster as a proxy for adaptive capacity. The findings provide a rigorous, evidence-based global perspective on the intensifying burden of heat-wave disasters and offer actionable insights for climate adaptation and disaster risk reduction policy.

Materials and Methods

Data Source

All data were obtained from the (EM-DAT; www.emdat.be), maintained by the Centre for Research on the Epidemiology of Disasters at the Université Catholique de Louvain, Belgium. EM-DAT compiles standardized information on natural and technological disasters from national authorities, United Nations agencies, non-governmental organizations, and peer-reviewed literature, applying multi-source validation and internal quality-control procedures before events are published (10).

Records categorized under the "heat-wave" disaster subtype within the "extreme temperature" disaster type were extracted for the full available period (1936–2024). EM-DAT applies the following predefined inclusion criteria for disaster registration: (1) ≥10 deaths; (2) ≥100 people affected; (3) declaration of a state of emergency; or (4) a request for international assistance. All records meeting at least one of these criteria were included without additional filtering. Events with missing temporal or geographic information were excluded. The absence or low frequency of recorded events in the early decades (particularly between 1936 and 1950) likely reflects limitations in global disaster reporting systems rather than indicating a true absence of heat-wave events. The dataset was accessed in April 2026 (version 2026-04-09) (11,12). This study utilized publicly available, de-identified secondary data from the EM-DAT. The dataset does not include any personal, identifiable, or sensitive human subject information. Therefore, according to institutional policies and international research ethics guidelines, formal ethical approval and informed consent were not required. The study was conducted in accordance with the Declaration of Helsinki and relevant research standards.

Operational Definitions and Derived Variables

A heat-wave disaster was operationally defined as a sustained period of anomalously high temperature resulting in human casualties or economic losses sufficient to meet EM-DAT inclusion criteria. For each event, EM-DAT provided the year of occurrence, affected country, continent/region, number of deaths, and reported economic damage in USD. Annual and decadal totals were generated directly from the reported event year. Decades were defined as ten-year intervals commencing with the year ending in zero (e.g., 1930–1939, 1950–1959).

"Deaths per disaster" was calculated by dividing total recorded deaths by total events for each country, serving as a proxy indicator of disaster vulnerability and national adaptive capacity. Death data were available for 314 of 344 events (91.3%); events lacking death records were retained in frequency analyses but excluded from mortality-specific calculations. Economic loss data were available for only 21 of 344 events (6.1%) and were not subjected to formal statistical analysis.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 29.0; IBM Corp., Armonk, NY, USA). Descriptive statistics-including total event counts, total and mean deaths per-event, median deaths per-event, and percentage distributions-were computed to characterize the global and regional burden of heat-wave disasters. The top 10 countries by event frequency and by total mortality, and the top 10 countries by mean deaths per disaster, were tabulated to assess geographic concentration. Because mean deaths per disaster is sensitive to the number of recorded events underlying each country's estimate, this ranking was additionally re-derived after applying minimum event-count thresholds of ≥3 and ≥5 events per country, as a sensitivity check on the stability of top-ranked countries.

Temporal trend analyses were conducted at two scales. At the annual-scale, simple linear regression was applied to the complete yearly time series (1936–2024), years with no recorded events were assigned a value of zero and were included in the regression, so that non-event years contributed to the trend estimate rather than being excluded. Because 35 of 89 years (39.3%) had zero recorded events, the annual-scale series was zero-skewed and right-skewed. Ordinary least-squares regression on such data can understate or distort the true trend. Therefore, the annual-scale was treated as a descriptive, conservative check rather than the primary inferential estimate, with the decadal-scale analysis serving as the principal trend test (Study Limitations). At the decadal scale, event counts and deaths were aggregated into nine decade-level observations (1930s through 2020s), a and simple linear regression was applied. For each model, the slope ($\beta \pm$ standard error), coefficient of determination (R(2)), and two-tailed p-value were reported. Statistical significance was defined as $\alpha=0.05$. Because the decadal-scale model is based on only nine decade-level observations, its statistical power is inherently limited, and the associated R(2) and p-values should be interpreted as a description of the aggregate trend rather than as evidence with the precision typically implied by a large-sample regression; it is reported alongside and is concordant in direction with the annual-scale model, and both are considered jointly rather than in isolation (Study Limitations). To evaluate whether the observed trends were artifacts of improved reporting completeness following EM-DAT's adoption of standardized inclusion criteria in the 1990s, a sensitivity analysis was conducted by repeating the annual-scale regressions on the 1990–2024 subset.

Seasonal distribution was assessed by tabulating events and deaths by month of disaster onset. Continental comparisons of per-event mortality were conducted as follows: First, the normality of the per-event mortality distributions was assessed using the Shapiro-Wilk test. All continental groups showed significant deviations from normality ($p<0.05$). The global distribution exhibited marked positive skewness (skewness =8.84; kurtosis =101.26), indicating a highly right-skewed, heavy-tailed distribution. Accordingly, comparisons were performed using the Kruskal-Wallis H test, followed by Dunn's post-hoc pairwise analysis with Bonferroni correction. P-values were adjusted using the Bonferroni correction. Statistical significance was defined as follows: $^{*}p<0.05$, $^{**}p<0.01$, and $^{*}p<0.001$ (ns: not significant).

Data Availability

All data are publicly accessible from EM-DAT (www.emdat.be). Derived datasets and code are available from the corresponding author upon reasonable request.

Results

Between 1936 and 2024, 344 heat-wave disasters were recorded in 75 countries across five continents. The earliest recorded event dates to 1936; no events were recorded between 1937 and 1950, which is consistent with the early-period reporting limitations of international disaster databases. Death data were available for 314 of 344 events (91.3%). In total, these disasters resulted in 350,425 deaths, with a mean of 1,116 deaths per disaster and a median of 132.5 deaths, reflecting a highly right-skewed distribution driven by a small number of catastrophic events. The single most lethal event was the 2010 Russian heat-wave (55,736 deaths).

Europe recorded both the highest number of events (n=184; 53.5% of the global total) and an overwhelming majority of fatalities (320,418 deaths; 91.4% of the global total), with a mean of 1,873.8 deaths per disaster. This striking concentration of mortality in predominantly high-income European nations, despite their relatively advanced health infrastructure, represents a paradox examined in detail in the Discussion. Asia ranked second in event frequency (n=102), but contributed only 5.9% of global mortality (20,777 deaths). The Americas, Africa, and Oceania accounted for 2.4%, 0.1%, and 0.1% of global deaths, respectively (Table 1, Figure 1).

The Kruskal-Wallis test confirmed that per-event mortality differed significantly across continents (H=29.80, $p<0.001$). Dunn's post-hoc analysis with Bonferroni correction identified Europe as significantly different from Asia (p=0.0005), the Americas (p=0.036), and Africa (p=0.033); all other pairwise comparisons were non-significant.

At the country level, India experienced the highest number of heat-wave disasters (n=32; 9.3% of the global total), followed by the United States of America (27), Pakistan (19), Japan (17), and France, Romania, and Belgium (11 each) (Figure 2).

In terms of mortality, the ranking differed markedly and was dominated by European nations. Italy recorded the highest total deaths (69,909; 19.9% of global fatalities), followed by the Russian Federation (56,032; 16.0%), Spain (41,597; 11.9%), France (37,509; 10.7%), and Germany (30,192; 8.6%). The top five countries-all in Europe accounted for 67.1% of global heat-wave deaths. India ranked seventh (13,291 deaths; 3.8%) despite leading in event frequency (Figure 2).

The mean number of deaths per disaster-a proxy indicator of disaster vulnerability and adaptive capacity varied markedly across countries. The Russian Federation recorded the highest deaths per-event (18,677.3; based on only n=3 recorded events), a figure largely driven by the 2010 heat-wave. Italy ranked second (7,767.7; n=9 events), followed by Spain (4,621.9; n=9 events), Germany (3,774.0; n=8 events), and France (3,409.9; n=11 events). All of the top 10 countries by this metric were European or high-income nations, underscoring a pattern that is strikingly distinct from cold-wave disasters, in which vulnerability is concentrated in lower-income countries.

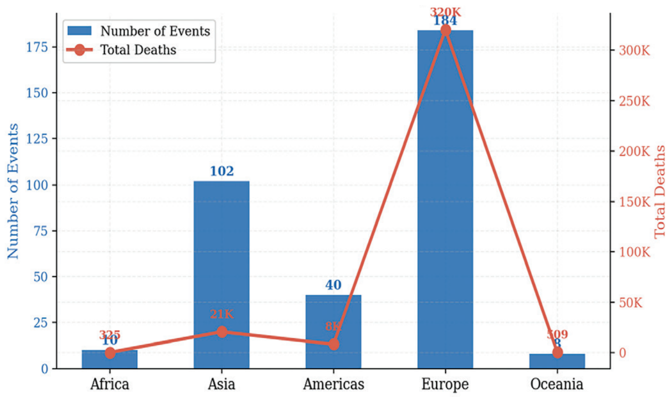

Figure 1. Heat-wave disasters and associated deaths by continent (1936–2024)

Linear regression revealed a statistically significant upward trend in annual heat-wave disaster frequency (β=0.170±0.028 events year -(1); p<0.001; R(2)=0.294). Years with no recorded events (n=35) were assigned a value of zero and included in the regression, providing a conservative estimate of the long-term trend. Annual mortality also showed a significant upward trend (β=204.1±55.1 deaths year -(1); p<0.001; R(2)=0.136). The comparatively low R(2) for mortality reflects the highly skewed, non-stationary nature of annual death counts (coefficient of variation =3.63), driven by the disproportionate influence of catastrophic outlier events such as 2003 (73,722 deaths), 2010 (56,448 deaths), 2022, and 2024, each of which exceeded 60,000 deaths. These levels were previously seen only during the most catastrophic single-year events on record (Table 2, Figure 3).

When aggregated by decade, both trends were considerably stronger. Disaster frequency increased from 2 events in the 1930s to 131 events in the 2020s (through 2024), with decadal models explaining 72.5% of variance in event counts (β=1.298±0.302; p=0.004; R(2)=0.725). Mortality rose from 1,693 deaths in the 1930s to 184,128 deaths in the 2020s, with decadal models

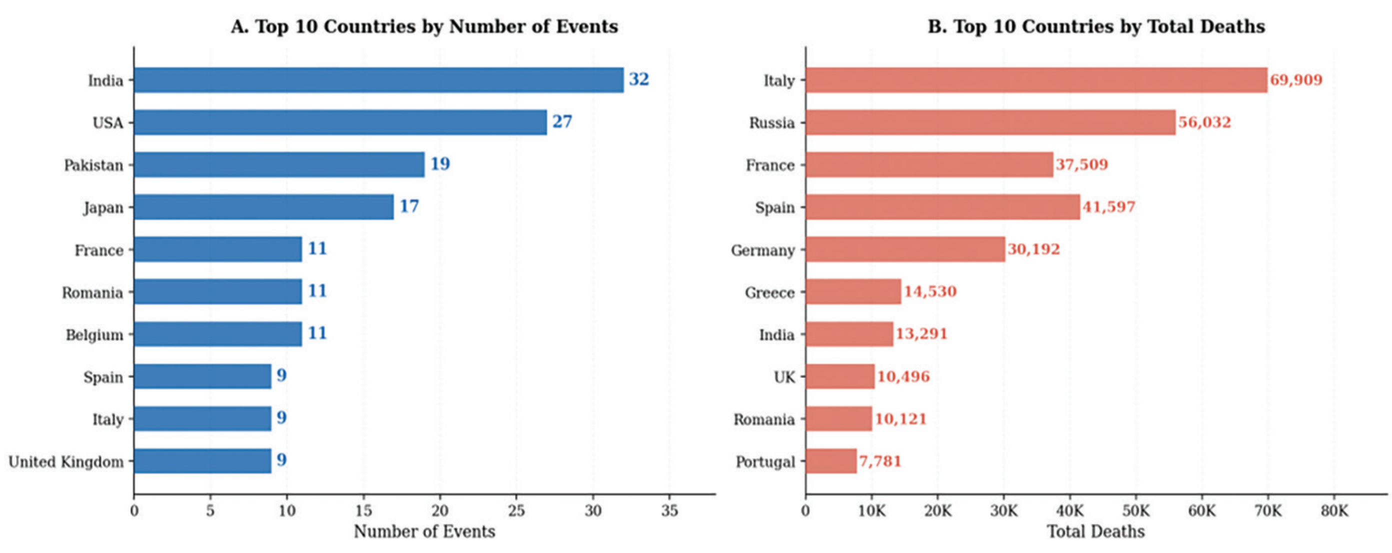

Figure 2. Country-level analysis of heat-wave disasters (1936–2024)

Table 1. Global and continental summary of heat-wave disasters

Continent	No. of disasters	Total deaths	Mean deaths/event	Share of global deaths (%)
Africa	10	325	36.1	0.1%
Asia	102	20,777	233.4	5.9%
Americas	40	8,396	209.9	2.4%
Europe	184	320,418	1,873.8	91.4%
Oceania	8	509	101.8	0.1%
Global total	344	350,425	—	100%

explaining 59.2% of variance in deaths (β=1,658.0±520.0; p=0.015; R(2)=0.592).

Because this metric is highly sensitive to the number of recorded events per country (Study Limitations), a sensitivity analysis was performed by re-ranking countries after applying minimum event-count thresholds of ≥3 and ≥5 events (Table 3). Under a ≥3-event threshold, Saudi Arabia (n=1) was excluded but the remaining ranking was unchanged, since the Russian Federation (n=3) still qualified. Under the more conservative ≥5-event threshold, however, the Russian Federation no longer qualified, and Italy became the top-ranked country (7,767.7 deaths per

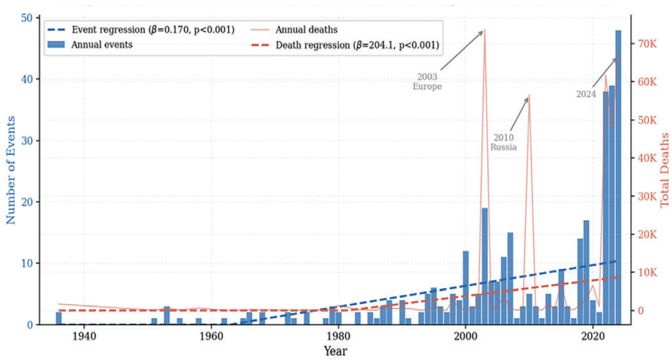

Figure 3. Yearly trends: heat-wave disaster count and total deaths with regression lines (1936–2024)

event), followed by Spain, Germany, France, Greece, Bulgaria, the United Kingdom, Portugal, Romania, and Croatia, all supported by ≥5 recorded events. This indicates that the Russian Federation's top ranking is not a stable, broadly supported vulnerability signature, but is instead driven almost entirely by a single catastrophic event (the 2010 heat-wave) and should be interpreted accordingly.

The sensitivity analysis restricted to 1990–2024 (35 years, of which only 1 had zero recorded events) confirmed both trends: disaster frequency continued to increase significantly (β=0.566±0.166 events year^{-}(1); p=0.002; R(2)=0.261), as did mortality (β=798.6±341.1 deaths year^{-}(1); p=0.025; R(2)=0.142). Notably, the post-1990 slope of disaster frequency was more than three times as steep as the full-period estimate (0.566 vs. 0.170 events year^{-}(1)), indicating that the upward trend is not an artifact of sparse early-period reporting and that, if anything, the full 1936–2024 series understates it.

All 344 events had a recorded start month. Heat-wave disasters exhibited a strongly seasonal pattern concentrated in the Northern Hemisphere summer months. July recorded the highest number of events (n=133; 38.7%), followed by June (n=86; 25.0%) and May (n=57; 16.6%). Collectively, May through August accounted for 87.8% of all events and 98.4% of global deaths. Notably, June recorded the highest mortality (135,717

Table 2. Trend analysis of global heat-wave disasters

Parameter	Time scale	β (slope ± SE)	R(2)	p value
Disaster counts vs. year	Annual	0.170 ± 0.028	0.294	<0.001
Death count vs. year	Annual	204.1 ± 55.1	0.136	<0.001
Disaster counts vs. decade	Decadal	1.298 ± 0.302	0.725	0.004
Death count vs. decade	Decadal	1,658.0 ± 520.0	0.592	0.015

β: Regression slope, SE: Standard error, R(2): Coefficient of determination. All four associations were statistically significant (p<0.05)

Table 3. Sensitivity of the deaths-per-disaster ranking to minimum event-count thresholds

Country	n events	Mean deaths/event	≥3 events	≥5 events
Russian Federation	3	18,677.3	Yes	No
Italy	9	7,767.7	Yes	Yes
Spain	9	4,621.9	Yes	Yes
Germany	8	3,774.0	Yes	Yes
France	11	3,409.9	Yes	Yes
Greece	8	1,816.2	Yes	Yes
Saudi Arabia	1	1,301.0	No	No
Bulgaria	5	1,274.0	Yes	Yes
United Kingdom	9	1,166.2	Yes	Yes
Portugal	7	1,111.6	Yes	Yes

The countries shown are the unfiltered top 10 by mean deaths per disaster (n = total recorded events per country). Shaded rows are excluded from the ranking under a ≥ 5-event threshold. Under ≥5, the ranking becomes: Italy, Spain, Germany, France, Greece, Bulgaria, United Kingdom, Portugal, Romania (920.1), and Croatia (675.0) deaths; 38.7%), exceeding that of July (88,684; 25.3%), reflecting the disproportionate impact of the 2003 European heat-wave, which peaked in June and in early August. No events were recorded in September or October across the entire study period; this may reflect both a lower frequency of meteorological heat-waves in post-summer months and potential underreporting or categorical-boundary effects that cause late-season events to fail to meet EM-DAT inclusion thresholds or historical subtype coding conventions (Figure 4).

Discussion

This study provides the first comprehensive, multi-decadal assessment of heat-wave disasters on a global scale using EM-DAT records spanning 1936–2024. A total of 344 disasters were recorded across 75 countries, resulting in 350,425 deaths. Both annual and decadal regression analyses confirmed statistically significant upward trends in disaster frequency and mortality, with the 2020s emerging as the deadliest decade on record (131 events; 184,128 deaths) a trajectory consistent with the accelerating warming documented in IPCC AR6 (8). Europe dominated the global burden, accounting for 91.4% of all heat-wave deaths despite representing 53.5% of recorded events. The Russian Federation recorded the highest mean deaths per disaster (18,677.3; n=3 events; see sensitivity analysis below), followed by Italy (7,767.7) and Spain (4,621.9), while India led in event frequency (32 disasters). The strong seasonal concentration of events in May–August (87.8% of events; 98.4% of deaths), with June recording the highest mortality despite July having the highest event count, reflects both the climatological drivers of Northern Hemisphere heat-waves and the disproportionate impact of the 2003 European event. Together, these findings underscore that heat-waves are not merely an environmental phenomenon but a rapidly intensifying public health crisis demanding urgent, globally coordinated action.

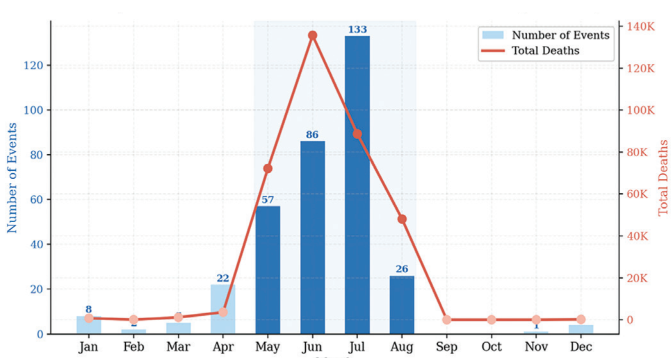

Figure 4. Monthly distribution of heat-wave disasters and associated deaths (1936–2024)

The observed increase in annual heat-wave disaster frequency (β=0.170 events year $^{-}$(1); R(2)=0.294) and the dramatic decadal acceleration-from 6 events in the 1950s to 131 in the 2020s are consistent with the robust physical attribution of heat extreme intensification to anthropogenic greenhouse gas emissions (8). At 2 °C of global warming, heat-mortality events that occurred once per century in the early 2000s are projected to occur at least once every five years (9). The particularly sharp rise in the 2020s reflects the confluence of record-breaking temperatures and growing human exposure through rapid urbanization and population growth. In 2023 alone, approximately 178,486 excess deaths were globally attributed to heat-waves, of which more than 54% were attributable to human-induced climate change (3), suggesting that EM-DAT-based disaster counts represent only the visible apex of a far larger heat-mortality burden.

One of the most striking findings is the extraordinary concentration of heat-wave mortality in Europe 91.4% of global deaths despite being composed predominantly of high-income nations with developed health infrastructure. This apparent paradox can be understood through several interconnected mechanisms. First, European populations are less physiologically and infrastructurally adapted to extreme heat than populations in tropical regions, with residential air-conditioning penetration remaining substantially lower in Northern and Central Europe (13). Second, Europe has one of the world's most rapidly aging populations: heat-related mortality rates are 768% higher among individuals aged 80 years and older than those aged 65–79 years (7). Third, rapid urbanization and the urban heat island effect amplify background temperatures within European cities, elevating local temperatures several degrees above surrounding rural areas and increasing population exposure (13). Fourth, the 2003 European heat-wave exposed critical systemic failures in early warning, social care coordination, and hospital surge capacity, producing more than 70,000 excess deaths (4).

Since 2003, European countries have progressively implemented national heat health action plans. Modeling suggests that without present-century societal adaptation, the 2023 European heat-related mortality burden would have been 80% higher (7). Nevertheless, the persistence of tens of thousands of heat-related deaths annually with an estimated 62,775 in Europe in 2024 alone (14) demonstrates that adaptation remains insufficient relative to the pace of warming. Projections indicate heat-related mortality in Europe is expected to increase by 103.7–135.1 deaths per million people per degree of global warming by 2100 under various emissions scenarios, with hotspots concentrated in Southern Europe and increasingly in Northern and Eastern Europe due to demographic aging (15).

The Russian Federation recorded the highest mean deaths per disaster (18,677.3), driven primarily by the catastrophic 2010 heat-wave a 44-day event that caused an estimated 55,736 deaths and was the deadliest single heat-wave disaster in the EM-DAT record. Several compounding factors explain this extreme lethality. Meteorologically, the 2010 event was unprecedented in both intensity and duration for Russia, with daytime temperatures reaching 38.2 °C in Moscow (16) values far outside the historical range to which infrastructure and populations were acclimatized. At the institutional level, Russia lacked a formalized national heat health action plan, early-warning dissemination was inadequate, and the public health response was delayed relative to the pace of the disaster (5). This case underscores that even in countries not typically classified as heat-vulnerable, the absence of preparedness systems can transform a meteorological extreme into a public health catastrophe. This ranking should, however, be interpreted with caution: it rests on only three recorded events, one of which, the 2010 disaster, accounts for 99.5% of the country's cumulative heat-wave deaths. When a minimum event-count threshold of ≥5 is applied as a sensitivity check (Results; Table 3), the Russian Federation no longer meets the threshold and Italy becomes the top-ranked country. The 2010 Russian heat-wave therefore remains a genuine and instructive catastrophic outlier, but the "highest mean deaths per disaster" ranking itself is a statistically fragile, single-event-driven statistic rather than evidence of a stable national vulnerability profile.

Asia contributed 102 events (29.7% of the global total) but accounted for only 5.9% of recorded deaths, with India alone accounting for 32 disasters. High event frequency in South Asia is driven by structural factors including dense agricultural labor forces with prolonged outdoor exposure, pervasive energy poverty limiting cooling access, rapid urbanization without adequate heat island mitigation, and health systems with limited surge capacity (17). Climate change has rendered South Asian heat-waves approximately 45 times more likely than in a pre-industrial climate (18), and wet-bulb temperatures in the Indus and Ganges River valleys are projected to approach or exceed the physiological survivability threshold of 35 °C under high-emission scenarios (19). The lower per-event mortality relative to Europe does not indicate lower vulnerability; rather, it reflects that many events fail to reach the catastrophic single-event threshold seen in European heat-waves, while chronic heat-mortality remains substantially underreported (17). India, Pakistan, and Bangladesh have taken initial steps toward heat action planning-most notably Ahmedabad's pioneering framework following the 2010 heat-wave (17) but implementation remains geographically uneven and insufficiently scaled relative to the magnitude of the risk (20).

The strong concentration of heat-wave disasters in May–August reflects the dominant role of Northern Hemisphere summer meteorology in shaping global patterns. The observation that June recorded the highest mortality (135,717 deaths; 38.7%) despite July having the highest event count is primarily attributable to the 2003 European heat-wave, which peaked in June and early August and produced catastrophic simultaneous mortality across multiple countries (4). This highlights that peak disaster impact does not necessarily coincide with peak event frequency, and that the epidemiological burden is disproportionately shaped by a small number of catastrophic outlier events. The complete absence of recorded events in September and October warrants careful interpretation: although Northern Hemisphere heat-wave frequency declines sharply after August, a reporting artifact cannot be excluded because late-season events may produce mortality below EM-DAT's inclusion thresholds. A distinct but related possibility is definitional rather than purely statistical: if earlier EM-DAT coding practice or contributing national sources implicitly bounded the "heat-wave" category to the conventional Northern Hemisphere summer window, late-season warm spells occurring in September or October may have been classified under a different hazard category (or omitted) rather being genuinely absent; this would produce the same zero count without reflecting a true climatological absence of events. Future research integrating EM-DAT records with meteorological reanalysis data (e.g., ERA5) would help disentangle genuine seasonal absence from potential underreporting or categorical-boundary effects.

Policy and Adaptation Implications

Heat-waves must be prioritized as a primary focus of climate adaptation. Early warning systems represent the highest-yield near-term intervention for reducing heat-wave mortality. France's national heat health action plan, implemented in 2004 following the catastrophic 2003 event, demonstrated measurable effectiveness during the 2006 heat-wave, where observed mortality (2,065 deaths) was substantially lower than the predicted toll of 6,452 deaths had no plan been in place suggesting more than 4,000 deaths averted by the intervention (21). Japan's integrated heat stroke prevention framework and Australia's state-level heat action plans similarly demonstrate that structured early-warning governance can substantially reduce per-event lethality (18). However, a global assessment found that cities in high- and upper-middle-income countries described full early warning systems nearly three times more often than those in lower-income countries (22), highlighting a critical equity gap that must be addressed through international technology transfer and climate finance, consistent with the Sendai Framework for Disaster Risk Reduction 2015–2030 (23).

Investment in passive cooling infrastructure-such as urban green spaces, reflective building surfaces, natural ventilation design, and access to affordable air-conditioning-is necessary even in high-income settings. For South Asia and sub-Saharan Africa, expanding access to cooling while reducing energy poverty represents the most critical near-term intervention pathway. Heat-wave risk must be mainstreamed into national adaptation plans under the Paris Agreement and integrated with urban planning, healthcare system preparedness, and social protection frameworks.

Study Limitations

The principal strength of this study is its comprehensive temporal coverage (1936–2024) and its use of a globally standardized, publicly accessible disaster database, enabling consistent comparison across decades and continents (10). Several limitations warrant consideration. EM-DAT relies on secondary reporting, and underreporting is a recognized limitation, particularly in low-income regions. Indirect heat-related deaths are substantially underreported, indicating that the true mortality burden far exceeds EM-DAT estimates. Economic damage data were available for only 21 of 344 events (6.1%), precluding assessment of the financial burden. The database also lacks meteorological parameters-such as maximum temperature, duration, and humidity-that would allow direct linkage between physical hazard intensity and health outcomes. Notably, the deaths per disaster metric is sensitive to the number of recorded events per country: countries with a single recorded event (e.g., Saudi Arabia, n=1) will have their mean entirely determined by that event, potentially inflating or deflating the metric relative to countries with multiple events. This limitation should be considered when interpreting cross-country comparisons; it is addressed quantitatively via a minimum event-count threshold sensitivity analysis (Table 3).

An important caveat is the improved observational coverage and reporting accuracy since the 1990s, when EM-DAT adopted standardized inclusion criteria. This likely contributes significantly to the observed increase in recorded disaster frequency, particularly in earlier decades and should be explicitly considered when interpreting long-term trends. To address this, a sensitivity analysis restricted to post-1990 data-the period of more consistent reporting-was conducted and confirmed both trends, indicating that the increases in disaster frequency and mortality are not solely artifacts of underreporting in earlier periods. Two further statistical limitations should be noted. First, 39.3% of years (35/89) in the annual-scale series had zero recorded events; this zero-inflation and marked right-skewness mean that ordinary least-squares regression may not fully capture the underlying trend, and count-based models (e.g., Poisson or negative binomial regression) would be a more statistically appropriate approach for future analyses of this series. Second, the decadal-scale regression relies on only nine aggregated observations; estimates of R(2) and p from so few points have limited statistical power and should be regarded as descriptive of the aggregate trend rather than high-precision inferential estimates. We present it as a corroborating, not stand-alone, analysis alongside the annual-scale model. Finally, EM-DAT does not record age- or sex-disaggregated mortality data, which precludes the calculation of age-adjusted mortality rates or sex-stratified analyses. Both approaches are near-standard in heat-mortality epidemiology and would have allowed direct comparison with demographic-adjustment studies (7,13). This represents an important gap that could be addressed by linking EM-DAT records to national vital statistics or WHO mortality databases in future work. Future research should integrate EM-DAT records with gridded climate reanalysis products and incorporate socioeconomic indicators-including air-conditioning penetration, age structure, urban heat island intensity, and health-system capacity-into multivariate vulnerability models to enable more granular global risk assessment (24).

Conclusion

Between 1936 and 2024, 344 heat-wave disasters caused 350,425 deaths across 75 countries, with both the frequency of disasters and mortality increasing significantly over the period. The 2020s have already surpassed all previous decades in the number of events and deaths, reflecting the accelerating impact of anthropogenic climate change. Europe's disproportionate burden-91.4% of global deaths-demonstrates that economic development alone does not confer heat resilience, while Asia's high event frequency underscores the distinct vulnerability of densely populated, rapidly urbanizing regions with limited adaptive capacity.

These findings underscore the need for urgent action. Heat-waves are increasing in frequency, intensity, and lethality. Strengthening early warning systems, expanding equitable access to cooling infrastructure, and mainstreaming heat risk into national adaptation frameworks and urban planning are essential priorities. International cooperation and climate finance directed toward the most vulnerable populations are indispensable if the goals of the Sendai Framework, the Paris Agreement, and Sustainable Development Goal 13 are to be achieved. Heat-waves are already among the deadliest natural hazards globally, and without rapid and coordinated adaptation, their impact is expected to escalate beyond the capacity of current health and disaster response systems.

Ethics

Ethics Committee Approval: This study utilized publicly available, de-identified secondary data from the EM-DAT (Emergency Events Database). The dataset does not include any personal, identifiable, or sensitive human subject information. Therefore, according to institutional policies and international research ethics guidelines, formal ethical approval and informed consent were not required. The study was conducted in accordance with the Declaration of Helsinki and relevant research standards.

Informed Consent: Not applicable. The study was based exclusively on publicly available, de-identified secondary data and did not involve direct participation of human subjects; therefore, informed consent was not required.

Footnotes

Conflict of Interest: No conflict of interest was declared by the author.

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