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Original Article

Excess Mortality from Multiple Causes During a Heat Wave in Brazilian States

Excesso de Mortalidade por Múltiplas Causas Durante Onda de Calor em Estados Brasileiros

Exceso de Mortalidad por Causas Múltiples Durante una Ola de Calor en los Estados Brasileños

Authorship

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Abstract

Objective: To estimate all-cause excess mortality during the 7–12 February 2024 heat wave in the Brazilian states identified by the National Institute of Meteorology (INMET) -Paraná, Rio Grande do Sul and Roraima-, to characterize its distribution across underlying causes of death, and to compare the declared and the affected areas. **Method:** Time-stratified case-crossover design using conditional Poisson likelihood on microdata from the Brazilian Mortality Information System. The exposure window was the one pre-specified by the INMET technical note, published before this analysis. Case days: 7–15 February, official window plus a zero-to-three-day lag; controls: remaining days of the month. Temporal and spatial negative controls were applied. **Results:** A total of 4,558 deaths were observed against 4,341 expected: relative risk 1.077 (95%CI 1.039–1.117), approximately 217 excess deaths. Negative controls were null. The excess was distributed across nearly all ICD-10 chapters, with no concentration in any, sparing neoplasms (0.980) and with no gradient by education or age. X30 recorded zero deaths. **Conclusion:** Officially recognized extreme events constitute a useful analytical unit, complementary to time-series studies, for investigating the health impact of heat waves.

Descriptors: Extreme Heat; Mortality; Death Certificates; Health Information Systems; Climate Change.

Resumo

Objetivo: Estimar o excesso de mortalidade por todas as causas durante a onda de calor de 7 a 12 de fevereiro de 2024 nos estados brasileiros apontados pelo Instituto Nacional de Meteorologia (INMET) -Paraná, Rio Grande do Sul e Roraima-, caracterizar sua distribuição por causa básica e comparar a área declarada com a atingida. **Método:** Delineamento caso-cruzado com estratificação temporal e verossimilhança condicional de Poisson sobre microdados do Sistema de Informações sobre Mortalidade (SIM). A janela foi a pré-especificada pela nota do INMET, anterior a esta análise. Dias-caso: 7 a 15 de fevereiro, com defasagem de zero a três dias; controles: demais dias do mês. Aplicaram-se controles negativos temporais e espaciais. **Resultados:** Observaram-se 4.558 óbitos contra 4.341 esperados: risco relativo 1,077 (IC95% 1,039–1,117), aproximadamente 217 óbitos em excesso. Os controles negativos foram nulos. O excesso distribuiu-se por quase todos os capítulos da CID-10, sem concentração em nenhum, poupando neoplasias (0,980) e sem gradiente por escolaridade ou idade. X30 registrou zero óbitos. **Conclusão:** Eventos extremos oficialmente reconhecidos constituem unidade analítica útil, complementar às séries temporais, para investigar o impacto sanitário de ondas de calor.

Descritores: Calor Extremo; Mortalidade; Atestado de Óbito; Sistemas de Informação em Saúde; Mudança Climática.

Resumen

Objetivos: Estimar el exceso de mortalidad durante la ola de calor del 7 al 12 de febrero de 2024 en los estados brasileños señalados por el Instituto Nacional de Meteorología (INMET) -Paraná, Rio Grande do Sul y Roraima-, caracterizar su distribución por causa básica y comparar el área declarada con la afectada. **Método:** Diseño caso-cruzado con estratificación temporal y verosimilitud condicional de Poisson sobre microdatos del Sistema de Información sobre Mortalidad (SIM). La ventana fue la preespecificada por la nota del INMET, previa a este análisis. Días-caso: 7 al 15 de febrero, con retardo de cero a tres días; controles: resto del mes. Se aplicaron controles negativos temporales y espaciales. **Resultados:** Se observaron 4.558 defunciones frente a 4.341 esperadas: riesgo relativo 1,077 (IC95% 1,039–1,117), unas 217 defunciones en exceso. Los controles negativos fueron nulos. El exceso se distribuyó por casi todos los capítulos de la CIE-10, sin concentración en ninguno, exceptuando neoplasias (0,980), sin gradiente por escolaridad ni edad. X30 registró cero defunciones. **Conclusión:** Los eventos extremos oficialmente reconocidos constituyen unidad analítica útil, complementaria a las series temporales, para estudiar las olas de calor.

Descriptores: Calor Extremo; Mortalidad; Certificado de Defunción; Sistemas de Información en Salud; Cambio Climático.

INTRODUCTION

Extreme heat waves are among the major contemporary challenges facing public health, and assessing their effects on mortality is essential for informing climate change adaptation policies. In Brazil, this issue has become urgent in light of intense El Niño events and the high probability of extreme weather events.

Quantifying this impact, however, faces a structural obstacle: heat-related deaths are virtually never recorded as such. Chapter XX of the International Classification of Diseases (ICD-10) includes code X30 (exposure to excessive natural heat), but its use in Brazilian death certificates is near zero, even during periods and in locations where extreme events are documented by the meteorological authority. The consequence is methodological rather than political: if heat does not appear as the underlying cause, the outcome of any study must be all-cause mortality, and attribution comes to depend entirely on the study design, not on clinical records.

Added to this is a rarely tested assumption. The literature on heat and health has focused primarily on cardiovascular outcomes: in a systematic review of 237 studies conducted in 43 countries, cardiovascular disease is the most studied specific outcome, with 61 studies, second only to all-cause mortality, with 65(1). This focus assumes that the effect of heat is concentrated in this area. If, on the contrary, heat acts as a nonspecific trigger in individuals with reduced physiological reserve, the excess should be dispersed across many causes—and studies restricted to the circulatory system would underestimate the impact. Despite the widespread use of time series to estimate the average effect of temperature on mortality, officially recognized individual extreme events remain under-explored as an analytical unit in mortality epidemiology.

On March 7, 2024, the National Institute of Meteorology (INMET) published a technical note describing the extreme events of February of that year(2). The document identifies, between the 7th and 12th, the first heat wave of 2024, with maximum temperatures exceeding 39 °C, and notes that the extreme heat occurred mainly in areas of Paraná, Rio Grande do Sul, and Roraima. This is the height of summer in the southern part of the country—high absolute heat, not a relative anomaly of a cold season. The time frame analyzed in this study is the one stated in this note, which was published prior to any examination of mortality data.

This study is, by design, an event-based epidemiological investigation. Similar to studies of natural disasters and outbreaks, the unit of analysis is a specific extreme event, delimited in time and space, officially recognized, and accompanied by weather warnings issued during its occurrence(2). Extreme events are not equivalent to one another—they differ in duration, extent, intensity, season, and exposed population—and analyzing each episode before pooling evidence across them preserves the variation that is relevant to planning. Event-centered studies also allow for the timely generation of evidence to inform the health system's response.

The study aims to estimate excess all-cause mortality during the time window officially declared by INMET in the states it identified; to characterize the distribution of this excess by underlying cause of death, testing the hypothesis of diffuse excess against that of excess concentrated in cardiovascular causes; and to examine the extent to which the geographic delineation provided by the technical note corresponds to the area where the excess occurred.

METHOD

Study Type and Data Source

An observational case-crossover study with temporal stratification, conducted using public microdata from the Ministry of Health's Mortality Information System (SIM) for the years 2014 through 2024 (the last year with consolidated final data).

The territorial grid was obtained from the Brazilian Institute of Geography and Statistics (IBGE) locality database. This report follows the recommendations of the STROBE checklist for observational studies.

Definition of Exposure

The event was defined based on INMET's official technical classification—February 7–12, 2024—and not on our own climatological reconstruction. This is a design choice: the goal is not to redefine the meteorological event, but to quantify its impact from the moment it was operationally recognized by the national authority. Applying an independent algorithm, such as the Excess Heat Factor or a percentile threshold, would address a different question. Two properties arise from this choice: First, only by using the declared area is it possible to verify whether the official delineation corresponds to the actual distribution of the excess; Second, the window was established by third parties in a published document without access to the mortality data subsequently analyzed, which amounts to an external prespecification of exposure and eliminates the possibility that it was chosen to produce a specific result.

Design and Strata

Each death serves as its own reference: exposed and unexposed days within the same stratum are compared, which by design eliminates confounding by characteristics that do not vary within that stratum—age composition, socioeconomic structure, service coverage, secular trends, and seasonality across months.

The stratum was defined by state, year, month, and day of the week. Case days were February 7–12, 2024, plus a lag of zero to three days, resulting in the window of February 7–15; control days were the remaining days of February 2024, on the same day of the week and in the same state. The primary outcome was all-cause mortality in Paraná, Rio Grande do Sul, and Roraima. The analysis was conducted at the state level: the municipalities mentioned in the technical note report between 14 and 145 deaths per month, which is insufficient for any statistical test.

Time Lag

A lag of zero to three days was specified in writing prior to any analysis for three reasons. Acute heat stress leads to decompensation within hours to a few days, and a multicenter study observed that the association between heat waves and mortality emerges acutely and lasts three to four days(3).

Temporal stratification controls for seasonality across months but not for trends within a month; thus, longer windows increase bias due to this trend.

Finally, February has 29 days, and a nine-day window leaves about three control days per day-of-the-week stratum. The complete profile of time lags is reported as a diagnostic feature, not as a selection criterion.

Estimator

Conditional Poisson likelihood. Conditioning on the total number of deaths in the stratum, the number of deaths on exposed days follows a binomial distribution, with a parameter

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that is a function of the relative risk (RR) and the ratio of exposed to unexposed days. The 95% confidence intervals (95% CI) were obtained using the Wald approximation of log(RR).

In case-crossover designs, conditional logistic regression predominates; the conditional Poisson likelihood is the equivalent formulation for data aggregated by day, offering computational advantages[4]. For small counts, exact conditional inference was used, with the null distribution obtained by convolution, the p-value calculated as mid-p, and the confidence interval determined by inversion of the test.

Secondary Outcomes, Stratifications, and Controls

Five causes were prespecified—circulatory (I00–I99), respiratory (J00–J99), chronic noncommunicable diseases, external causes (V01–Y98), and renal/genitourinary (N00–N99), the latter based on prior evidence of heat-associated kidney injury[5]—and three stratifications: age 80 years or older, death at home, and educational level. External causes were not disaggregated by intent due to documented coding drift during the period.

Temporal negative controls (same calendar days from 2014 to 2023), spatial controls (four states in the Southeast not listed in the note), a mortality shift test with an external reference to the month, and an internal control for long-term causes were applied. Concurrent epidemics were verified directly. Santa Catarina and Mato Grosso do Sul were incorporated after the primary analysis, in an explicitly post hoc analysis.

Ethical and Integrity Considerations

Public, anonymized, and aggregated data were used, without individual identification, thus exempting the study from review by a Research Ethics Committee under the terms of CNS Resolution No. 510/2016.

RESULTS

Excess Mortality

All 21 possible strata were informative, comprising 14,080 deaths in February 2024. There were 4,558 deaths compared with 4,341.4 expected, corresponding to a RR of 1.077 (95% CI 1.039–1.117; $p<0.001$) and approximately 217 excess deaths over nine days. The three states were homogeneous ($I^2 = 0\%$), which allows for a pooled analysis (Table 1).

Table 1 - Excess mortality from all causes during the heat wave, by state and by lag window. Paraná, Rio Grande do Sul, and Roraima, February 2024.

Excerpt	Observed	Expected	RR	95% CI
Pool of the three units	4,558	4,341.4	**1.077**	1.039–1.117
Rio Grande do Sul	2,367	2,224.2	1.100	1.046–1.156
Paraná	2,122	2,054.4	1.050	0.996–1.107
Roraima	69	62.8	1.158	0.860–1.561
Phase shift 0 (Feb. 7–12)	3,135	2,901.0	1.109	1.065–1.155
Gap 0–1 (Feb. 7–13)	3,653	3,402.0	1.100	1.059–1.142
Gap 0–3 (Feb. 7–15)	4,558	4,341.4	1.077	1.039–1.117
Gap 0–7 (Feb. 7–19)	6,386	6,302.9	1.025	0.991–1.060

Source: Prepared by the author (2026).

The effect was greatest at a lag of zero and declined monotonically until it reached zero at seven days (Table 1). This pattern is consistent with acute stress and is the opposite of what intramonal trend contamination would produce, in which the RR would increase as the window widened. The daily time series corroborates this: the ratio of observed deaths to the average for the same day of the week in 2014–2023 rises from 1.06 on February 7 to 1.25 on February 11 and 1.23 on February 12—the last day of the surge—returning to baseline on February 15.

Distribution by Cause

The excess was distributed across virtually all categories consistent with acute decompensation, with none accounting for more than 21% of the total (Table 2). There were 25 tests, of which 10 had $p<0.05$ compared to the 1.2 expected by chance, and none survived the Bonferroni correction—an expected result, since the observed excess constitutes precisely an effect distributed across multiple categories, rather than concentrated in any single one.

The internal control was satisfied: neoplasms had an RR of 0.980 (0.905–1.060), mental disorders 0.964, and digestive disorders 0.981—chapters whose pathophysiology is incompatible with acute onset. A counting artifact would have elevated all chapters collectively, including neoplasms, which did not occur.

Table 2—Relative risk and absolute contribution to excess mortality, by ICD-10 chapter. Paraná, Rio Grande do Sul, and Roraima, February 7–15, 2024.

Chapter	RR	95% CI	Excess	% of total
Circulatory (I00–I99)	1.067	0.992–1.147	+46.5	21
Respiratory (J00–J99)	1.139	1.015–1.277	+37.1	17
Endocrine (E00–E90)	1.225	1.061–1.414	+36.7	17
External causes (V01–Y98)	1.125	1.008–1.256	+36.6	17
Infectious (A00–B99)	1.192	1.020–1.392	+27.2	13
Renal/genitourinary (N00–N99)	1.249	1.033–1.510	+22.9	11
Nervous system (G00–G99)	1.109	0.955–1.289	+17.3	8
Mental (F00–F99)	0.964	0.704–1.319	−1.5	−1
Digestive (K00–K93)	0.981	0.837–1.149	−3.0	−1
Neoplasms (C00–D48)	**0.980**	0.905–1.060	**−12.8**	**−6**
Total, all causes	**1.077**	1.039–1.117	**+216.6**	**100**

Source: Compiled by the author (2026).

Heat was not observed as the underlying cause. Code X30 recorded zero deaths in all states and on all days analyzed. Code E86, for volume depletion, recorded a single death during the study period.

Negative controls

The crude grouping of the years of false exposure showed high heterogeneity ($I^2 = 94\%$), attributable to two clearly inappropriate years: February 2014, which had an actual heat wave, and February 2021, during a rising wave of COVID-19. Excluding these years, the window bias in February is null.

Spatial control, applied to the four states in the Southeast - none of them listed in the note-, was also null (RR 1.011; 95% CI 0.992–1.030). The contrast between the listed states and the control states yielded a ratio of RRs of 1.065 (95% CI 1.023–1.110; $p=0.002$) (Table 3). The RR remained stable regardless of whether the control days were restricted to those preceding the window (1.077), those following the window (1.084), or those far beyond the window (1.059).

Table 3 - Temporal and spatial negative controls, February 2014 to 2024.

Control	Observed	Expected	RR	95% CI
False exposure, 2014–2023	40,823	40,590.5	1.009	0.997–1.021
False exposure, excluding 2014 and the pandemic	22,034	22,054.3	0.999	0.982–1.015
States not listed (SP, MG, RJ, ES)	16,354	16,236.2	1.011	0.992–1.030
States listed (PR, RS, RR)	4,558	4,341.4	1.077	1.039–1.117

Source: Prepared by the author (2026).

Mortality Shift

The study design does not allow for quantifying shifts within the month: given the total for each stratum, the sum of the monthly deviations is zero by construction, so a deficit after the event window would be purely arithmetic. The test requires an external reference. Therefore, we compared the ratio of deaths from February 16 to March 31 to those in the period prior to the event (January 5 to February 6) of the same year, contrasting 2024 with the control years (2015–2019 and 2023).

If the deaths during the window had merely been brought forward, 2024 would have shown a lower ratio than the controls. The opposite was observed: 1.457 in 2024 versus an average of 1.340 in the controls (standard deviation 0.034; z = +3.50). This result holds even when excluding dengue and COVID-19—whose incidence was rising during the period (1.435 versus 1.343; z = +2.94)—and when considering the circulatory and respiratory systems combined, where such a shift is classically described (1.454 versus 1.339; z = +3.76).

There is, therefore, no evidence of a compensatory deficit in the following six weeks. The excess observed in the subsequent period is not attributable to this heat wave—March 2024 saw other heat waves in the country—so the finding supports the absence of a deficit, not the presence of an additional excess.

Concomitant Confounders

February 2024 coincided with the onset of the largest dengue epidemic ever recorded in the country and with residual circulation of SARS-CoV-2. Neither explains the excess. The RR for dengue during the study period was 0.806 (95% CI 0.474–1.369) and that for COVID-19 was 1.122 (0.783–1.609). Above all, both showed an upward trend within the month—dengue with 17, 19, and 35 deaths in the first, second, and third thirds of February, respectively, and COVID-19 with 20, 47, and 70—which increases the number of control days in the second half and biases the estimator downward in a window at the beginning of the month. Excluding these two, the RR for infectious causes increased from 1.192 to 1.274 (1.061–1.529).

Education Level and Age

There was no gradient by educational level for any of the three pathways evaluated: heterogeneity among the five levels (p=0.40), linear trend (p=0.78), and contrast between low and high educational levels (p=0.84). Nor was there an age gradient (p=0.88) (Table 4).

The lowest detectable RR ratio among strata was 1.147, so the study excludes large but not moderate effect modification. Educational level was unknown in 17.6% of deaths, and this stratum had the highest RR in the dataset (1.140; p=0.002), with an uneven distribution across states.

Table 4 - Relative risk by educational level and age group. Paraná, Rio Grande do Sul, and Roraima, February 7–15, 2024.

Subgroup	n	RR	95% CI	p
No schooling	1,383	1.099	0.979–1.232	0.11
1 to 3 years	2,712	1.012	0.932–1.100	0.78
4 to 7 years	3,555	1.105	1.029–1.187	0.006
8 to 11 years	3,011	1.073	0.993–1.160	0.08
12 years or older	937	0.983	0.852–1.133	0.81
Education level unknown	2,482	1.140	1.047–1.242	0.002
0 to 39 years	–	1.108	0.990–1.241	0.08
Ages 40 to 59	–	1.096	1.004–1.197	0.04
60 to 79 years	–	1.034	0.977–1.094	0.24
80 years or older	–	1.115	1.047–1.188	0.001

Source: Prepared by the author (2026).

Spatial Distribution

The dose-response hypothesis based on peak temperature was not supported in this event. The mesoregion containing the municipalities with the highest recorded temperatures had an RR of 1.204 (0.994–1.459) compared to 1.088 in the rest of the state, a ratio of 1.107 (p=0.32).

The decomposition showed that the signal originated from a single municipality, whose daily series included four consecutive zeros between February 20 and 23—a probability of 7×10^{-6} under a Poisson distribution—while the rest of the state maintained normal counts on those days. Excluding that municipality, the others in the same microregion totaled 54 deaths compared with 50.1 expected (RR 1.123; p=0.50).

The mesoregions with an excess robust enough to survive the Bonferroni correction among 19 tests were the Porto Alegre Metropolitan Area (1.174) and North Central Paraná (1.183), neither of which was mentioned in the technical note.

Expanded Analysis

Santa Catarina, which was not mentioned in the note and is located between the two affected states in the South, had an RR of 1.057 (0.980–1.141) after correction for its own bias, making it indistinguishable from Paraná and Rio Grande do Sul (p=0.68) and distinct from the control states. The expanded group resulted in an RR of 1.073 (1.035–1.111), with approximately 271 excess deaths (Table 5).

Table 5 - Expanded analysis, showing crude results and results adjusted for the window bias measured in each unit, February 2024.

Group	Crude	Measured Bias	Adjusted	95% CI	p
Paraná and Rio Grande do Sul	1.076	0.999	1.077	1.034–1.120	0.0003
Santa Catarina (*post hoc*)	1.080	1.021	1.057	0.980–1.141	0.15
Expanded bloc (PR, SC, RS)	1.077	1.004	**1.073**	1.035–1.111	<0.001
Mato Grosso do Sul (control)	0.947	0.987	0.959	0.844–1.090	0.52

Source: Prepared by the author (2026).

DISCUSSION

The most significant finding of this study is not the magnitude of the excess but its distribution. Nine chapters of the ICD-10 contributed positively; none accounted for more than one-fifth of the total, and none survived correction for multiplicity on its own, while the chapters incompatible with acute onset remained unchanged.

This pattern is consistent with a fragility mechanism: heat stress acts as a nonspecific precipitating factor in individuals with reduced physiological reserve, and the cause recorded on the death certificate is the underlying disease, not the heat. The absence of a compensatory deficit in the following weeks indicates that the excess cannot be explained by the anticipation of imminent deaths, which is consistent with the diffuse pattern across causes and with the preservation of neoplasms: the heat triggered decompensation in individuals with reduced reserve, not in a population at the end of life.

This has three implications. The first is that, in this study, analyses restricted to cardiovascular outcomes would have captured only a minor portion of the impact: the circulatory system accounts for 21% of the excess, while 79% occurs outside of it. The assumption of cardiovascular concentration, which is prevalent in the literature[1], was not corroborated by the data from this study. The second is that, in this event, sentinel indicators based on specific causes showed limited utility, as the signal was diluted across many categories. The third is that cause-defined negative controls are invalid in this context, leaving validation through temporal, spatial, and long-term cause controls.

The observed composition is also consistent with what is known about pharmacological vulnerability to heat, since diuretics, antihypertensives, anticholinergics, and psychotropic drugs alter thermoregulation and are concentrated in the population with chronic disease[6], a hypothesis that cannot be tested with SIM data.

Absence of Heat in Underlying Cause Statistics

The finding of zero deaths coded as X30, in an event with an estimated excess of approximately 217 deaths, is this study's main contribution to the debate on surveillance. The explanation is clinical rather than bureaucratic: heat rarely causes death by overt hyperthermia in the general population, but rather by precipitating decompensation in those who already have chronic diseases. The physician correctly records the disease that led to death; the environmental condition that precipitated it has no specific field and is often not even known to the person filling out the document.

Four consequences arise from this: the magnitude of the problem is officially zero, which pushes the issue off the agenda for an artifactual reason; quantification requires an indirect and retrospective method, dependent on consolidated microdata, which becomes available with a delay of approximately one year, thereby precluding real-time estimates; attribution depends entirely on the survey design; and, without an official count, there is no baseline for evaluating contingency plans.

It is not proposed that the X30 form be filled out routinely, as the information is not available at the time of completion. A plausible solution is to routinely link mortality databases to meteorological data by municipality and date, treating heat exposure as an environmental variable to be cross-referenced, rather than as a cause to be reported—a technically feasible approach, since the SIM records the municipality and date of death, and INMET maintains a network of automatic weather stations with open-access data. This integration would also enable the development and validation of predictive models for population- and individual-level risk during future heat waves.

Official Delimitation and Area of Impact

The technical note lists three states based on the stations with the highest absolute maximum temperatures, and the results show that this list does not correspond to the distribution of excess mortality. Within the identified states, the municipalities with the highest peak temperatures were not where the deaths occurred, whereas the mesoregions with a robust excess are metropolitan and at low altitudes—a pattern consistent with studies documenting the specific effect of nighttime temperature on mortality[7] and with the effect of the urban heat island on minimum temperatures[8]. Outside of these, in the post hoc exploratory analysis, Santa Catarina showed an excess indistinguishable from that of the states mentioned.

This observation is not a criticism of INMET, whose report is a meteorological survey and does not aim to delineate areas of health risk, but rather a caution regarding the use of such documents: a contingency plan that adopted the list of three states as the definition of a risk area would exclude Santa Catarina and prioritize low-density border municipalities, to the detriment of the metropolitan regions where the excess was concentrated.

Position Regarding the Literature

Studies on heat and mortality are predominantly conducted using time series data, with the Distributed Lag Nonlinear Model being the most frequently employed analytical method in this type of study[1], and the multicenter study by Guo et al. among the primary methodological references in the field[3].

These designs estimate the average association between temperature and mortality over the course of years and do so effectively; the trade-off is that they dilute individual episodes into this average. No design is inherently superior to the other: both address distinct and complementary epidemiological questions.

The event-centered approach allows for a description of the latency structure, the composition by cause, the internal spatial distribution, and the correspondence between the reported area and the affected area—none of which can be obtained from an average annual risk.

Why a Single Event

The choice of this episode was not based on temporal availability, but on its simultaneous possession of characteristics that make it analyzable: a defined time period, official recognition, coverage across multiple states—which allows for internal comparison between affected and unaffected areas—and sufficient magnitude to warrant a specific assessment.

Added to this is a methodological argument: extreme events differ substantially from one another, and a pooled estimate of heterogeneous episodes produces an average whose interpretation depends on which events were included in the mix, obscuring the variation relevant to planning.

Analyzing each episode before pooling evidence across them preserves this variation and subsequently allows us to examine what explains it. The multi-event study is the natural next step, and in it, the reconstruction of exposure using an objective index becomes necessary, because comparing episodes requires a uniform criterion.

Limitations of the Study

The main limitation is one of scope and stems from the study design itself: the estimates are specific to this episode and depend on its intensity, duration, season, and the vulnerability of the population at that time; they do not allow for extrapolation of the RR of 1.077 to heat waves in general, nor do they permit the estimation of average annual risk or a continuous exposure-response relationship, which require multi-year data series. Reproducibility requires replication in other episodes, which will differ from one another—a heterogeneity that is the subject of investigation, not noise.

As for exposure, it is ecological and binary, with entire states classified as exposed, which dilutes the effect and suggests that the RR in the areas actually affected is higher than estimated; there is no link between death and measured temperature, and the results are not directly comparable to those of studies based on climatological indices.

As for the data, Roraima does not contribute meaningful information; causal inference is limited to the aggregate pattern; educational level is missing for 17.6% of deaths—the stratum with the highest RR in the dataset; the inclusion of Santa Catarina is post hoc; and the municipality of occurrence was used, with a sensitivity analysis by place of residence that did not alter the conclusions.

Contributions to Science

The study provides an estimate of excess mortality associated with an officially recognized extreme event in Brazil, with direct implications for surveillance: in this event, sentinel indicators based on specific causes proved to be of limited utility, and the health sector's response could not be calibrated using official counts of heat-related deaths.

By showing that the area with the highest recorded temperature does not coincide with the area of highest mortality, this study indicates that contingency plans should be guided by population exposure rather than by station rankings. Finally, the design employed here is reproducible using public data and can be applied to other extreme events, paving the way for the timely assessment of climate episodes relevant to public health.

CONCLUSION

This study suggests the feasibility of using officially recognized extreme events as an analytical unit for the epidemiological investigation of their impacts on mortality. The approach complements time-series-based studies, without replacing them, and can contribute to the rapid assessment of climate events of high relevance to public health, provided it is accompanied by the controls that support the attribution.

When applied to the heat wave of February 7–12, 2024, the analysis identified spatially specific excess mortality in the states identified by INMET, distributed across virtually all ICD-10 chapters consistent with acute decompensation, with no concentration in any specific cause, age group, or educational level. This pattern is consistent with population vulnerability and suggests that, in episodes such as this one, studies limited to cardiovascular outcomes capture only a minority of the phenomenon.

None of these deaths were recorded as heat-related. As long as heat exposure is not routinely cross-referenced with mortality databases, the impact of heat on health in Brazil will remain accessible only through isolated retrospective studies and will officially be considered zero. As a next step, we recommend linking mortality databases to data from weather stations by municipality and date, and replicating this study design for other extreme events—including February 2014, identified in this study as an episode of greater magnitude that has not yet been cataloged.

SUPPLEMENTARY INFORMATION

The source code for the analysis, the dashboards derived from the microdata, and the complete results of the municipal, microregional, and mesoregional analyses are deposited on Zenodo under DOI 10.5281/zenodo.22148457, available as open access (https://doi.org/10.5281/zenodo.22148457). Individual microdata are not redistributed: they are publicly available and obtained directly from DATASUS, and the repository includes the source of each file used, along with a checksum.

AUTHORS' CONTRIBUTION

Transparency in authors' contributions according to the CRediT Taxonomy.

Conceptualization	Fábio Luiz Vieira
Data Curation	Fábio Luiz Vieira
Formal Analysis	Fábio Luiz Vieira
Funding Acquisition	Not applicable
Investigation	Fábio Luiz Vieira
Methodology	Fábio Luiz Vieira
Project Administration	Not applicable
Resources	Not applicable
Software	Fábio Luiz Vieira
Supervision	Not applicable
Validation	Fábio Luiz Vieira
Visualization	Fábio Luiz Vieira
Writing - Original Draft Preparation	Fábio Luiz Vieira
Writing – Review & Editing	Fábio Luiz Vieira

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Artificial Intelligence	Artificial intelligence assistance (Claude, Anthropic) was used in three areas: writing and debugging the analysis code in Python; verifying the consistency of the microdata and checking citations; and drafting and revising the text. All analyses were performed on public microdata from the Mortality Information System, and their results were verified and curated by the author, who bears full responsibility for the content of the manuscript.

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The translation of this article was assisted by DeepL Translator artificial intelligence from the original version written in Portuguese (Brazil). The translated version was submitted to the editorial team for curation, consisting of a limited scope editorial review. Translations assisted by artificial intelligence may vary from the native language.

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