Natural Hazards Fatalities in Brazil, 1979–2019

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Abstract

The impact of natural hazards on nations and societies is a global challenge and concern. Studies worldwide have been conducted within and among countries, to examine the spatial distribution and temporal evolution of fatalities and their consequences in societies. In Brazil, no studies have comprehensively identified fatalities associated with all natural hazards and their singularities by decade, region, sex, age, and other victim characteristics. This study develops a deep analysis on the Brazilian Data Mortality of the Brazilian Ministry of Health, from 1979 to 2019, identifying the natural hazards that kill the greatest number of people in Brazil and its surrounding particularities. Lightning is the deadliest natural hazard in Brazil during this period, with a gradual decrease in the number of fatal victims. Hydrogeological fatalities increases from 2000, and the most fatalities develop from 2010 to 2019. Despite Brazil being a tropical country affected by severe droughts, extreme heat had the lowest number of fatalities, almost irrelevant when compared with that of other natural hazards. The period from December to March is with the higher number of fatalities, and the Southeast region is the most populous regions were the most are fatally affected. The number of male victims is double that of female victims, of all ages, and unmarried victims died the most. Thus, it is fundamental to recognize and make public the knowledge of different natural hazards' impacts on communities and societies, namely people and their livelihoods, to evaluate challenges and recognize opportunities to reduce natural hazards' impacts on Brazil.

Introduction

Natural hazards[1] are recurring phenomena (WMO 2021). They can be, for example, a violent storm over an uninhabited region with no human consequences and can be triggers to disasters, to serious disruption of the functioning of a community or a society at any scale (UNISDR 2017), that negatively affect individuals at the global, national, societal scales.

Death due to natural hazards is the ultimate consequence and not only is associated with the nature and extent to which a system is exposed to a natural event but also linked to socioeconomic and environmental contexts and conditions (IPCC 2022). Individuals have the capability and systems' conditions to cope, manage, and respond to such adverse conditions.

The increase in frequency and intensity of climatic extremes amplifies the severity of natural hazards (IPCC 2022; IPCC 2020) and, consequently, the challenges that social systems must manage, especially individuals who experience vulnerabilities in their daily lives (CRED-UNISDR 2018).

In Brazil, the number of individuals affected by natural hazards is high. Between 2001 and 2021, approximately 53 million people were affected by landslides, storms, droughts, floods, flash floods, and dam collapses (EM-DAT 2021). Additionally, highly vulnerable regions will increase in vulnerability because of increases in climate and weather extremes due to climate change (Marengo 2021).

Despite the number of deaths due to weather-, climate-, and water-related disasters decreasing from 1970 to 2019 (WMO 2021), two essential questions require answers: What is the most dangerous category of natural hazards? Which individuals are the most fatally affected by natural hazards? Thus, this study aims to provide, for the first time in Brazil, insights into temporal evolution, spatial distribution, and induced fatalities patterns differentiated by sex, age, and marital status in the Brazilian population from 1979 to 2019.

1.1 Scientific knowledge

Within the broader field of disaster and environmental change research, studies have been conducted on natural hazards impacts, measuring and qualifying fatal victims and their circumstances of mortality.

Many empirical studies on mortality due to natural hazards have been conducted from perspectives based on different scales of analysis, differentiated by the category of natural hazards and/or focused on a single event.

Global studies have estimated human losses, identifying the impacts of all categories of natural hazards on the human population and population subgroups, suggesting global trends. In the 1990s, Sapir (1993) provided insights into patterns and trends in disaster mortality and morbidity generated by natural and man-made hazards, affirming that they occur neither equally nor at random. Neumayer and Plumber (2017) indicate to economic, cultural, and socially constructed gender-specific vulnerabilities as responsible for different strands of global male and female mortality. Zagheny, Muttarak and Striessnig (2015) correlated the level of economic development of nations with the age and sex of fatal victims of hydro-meteorological disasters.

On the global scale, some studies have focused on a specific category of natural hazard, evaluating the possible mortality patterns, reasons for their occurrence, and the most affected subgroups. Froud and Petley's (2018) analysis of global fatal landslides indicates a strong seasonal rainfall pattern throughout the annual cycle, and the most prevalent fatalities occurred in densely occupied urban centers in the poorest countries. Likewise, Doccy et al. (2013) suggested, based on a historical review of floods events from 1980 to 2009, a global increase in the frequency of flood events, and mortality varying annually and often concentrated around large-scale events. Holle (2016) analyzed how global lightning fatalities differ between developed and lesser-developed countries and suggested higher education and awareness as measures to reduce the number of deaths. Additionally, a comparative multi-country analysis was conducted in Latin American cities to assess whether the risk of heat-related mortality is associated with age, sex, and disease status, amplified by social disparities (Bell et al. 2008).

Results of the global-scale analysis of natural hazards fatalities have demonstrated what is already known: the poorest nations and the most disadvantaged populations are those that suffer most severely (Hamza 2015) and have the largest number of deaths[2] (CRED-UNISDR 2018).

Research based on multi-hazards data in a single country can compare mortality data among categories of natural hazards (i.e. floods, landslides, lightning, storms, hurricanes, extreme temperatures as cold and heat waves), identifying the category that kills the most people, the most affected regions, and the sociodemographic characteristics of the victims, converting national data mortality into knowledge.

An analysis conducted by a group of researchers in the United States (Thacker et al. 2008) highlights that extreme temperatures in the United States cause more deaths than other natural hazards. Despite this information, the amount of media attention and disaster relief resources is much higher for hurricane, storm, flood, and tornado events than for extreme temperatures. A study of Mexico (Jauregui-Dias et al. 2019) identified that from 2000 to 2015, the mortality from extreme weather events in Mexico remains constant. The differences between sex and age vary by the type of disaster and because of the sex division of labor. Mahapatra et al. (2018) analyzed Indian data mortality by all natural hazard causes from 2001 to 2014 for all states and union territories of India and found no consistent pattern in death rates. Extreme weather events vary in magnitude and region annually, and males are at greater risk of death than females due to their participation in outdoor work.

A study of South Korean (Myung and Jang 2011) analyzed the causes of fatalities due to meteorological disasters, the demographical characteristics of the victims, and regional distribution and found that the majority of fatalities are caused by floods due to drowning and that the place of death is distinct for male and female victims. Additionally, a study of natural hazards loss of life in Switzerland, from 1946 to 2015 (Badoux et al. 2016), recognized that most fatalities occur due to avalanches, affecting male and female victims differently. The Badoux et al. (2016) study also recognizes that improved forecasting, process detection, and warning systems are mainly responsible for the reduction of mortality.

Other authors have investigated natural hazards mortality through multi-hazards lenses, and a group of studies has focused on mortality due to specific categories of natural hazard at the national scale, with a long-term dataset, or focus on specific events. Coates (1999) was the first to publish a study on flood fatalities in Australia from 1788 to 1996 and determined that the reduction in fatalities was due to improvements in warning systems and rescue services. Ashley and Ashley (2008), based on US mortality data from 1979 to 2004, attributed the high number of flood fatalities to “people walking purposely" through water. A study of Greece demonstrated the circumstances under which most of the flood fatalities, from 1970 to 2009, occur: during nighttime, in outdoor areas, mostly vehicle-related, and from drowning (Diakakis and Deligiannakis 2017). A study of landslide and flood fatalities in Italy from 1965 to 2014 correlated the age and sex of victims to the circumstances of their deaths (Salvati et al. 2018).

Additionally, case studies have assessed the singularities of the cyclone of 1991 in Bangladesh (Bern et al. 1993), the 2003 heat wave in France (Poumadre et al. 2005), the 2002 landslide in Chuuk, Micronesia (Sanchez et al. 2009), and the 1931 hurricane, and floods in Fiji (Yeo and Blong 2010)

[1] A hazard is qualified as “a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation” (UNDRR 2020)

[2] The Centre for Research on the Epidemiology of Disasters (CRED) and the UN Office for Disaster Risk Reduction reports that in 2015 and 2018, there were a relatively low number of deaths in low-income countries and suggest that these nations have under-reported this number (CRED-UNISDR 2015)

Natural Hazard-caused Mortality In Brazil

Located mostly in a tropical area with a hot climate, with a large variation in precipitation, from large accumulation to rainfall deficits, along the seasons and through the national territory (Debortoli et al 2016), Brazilian mortality due to natural hazards are characterized by storms, floods, flash floods, landslides, droughts, debris flow, heatwaves, extreme cold, tornados, erosion, forest fires (CEPED 2012), and lightning. Brazil is also subject to dam collapses.

Data on mortality have been registered in Brazil since 1975 by the Ministry of Health[3], providing microdata by age, sex, cause, and other fatality characteristics. Specific data on disasters events and the number of deaths have been published since 1992 by the University Centre for Disaster Studies and Research[4], at the Federal University of Santa Catarina, in association with the National Secretariat of Civil Defense. Internationally, the International Disasters Database termed as EM-DAT, maintained by the Centre for Research on the Epidemiology of Disasters, Université Catholique de Louvain, Brussels[5], also provides a dataset for Brazil, especially the number of people killed by a particular type of disaster. Each system is managed by a different organism and uses a different system of data collection, classification, and publishing.

In Brazil, extreme weather events and their medium and long-term impacts, materialized in diseases and health problems, are poorly evaluated and are misunderstood, and mortality associated with them is not registered as a consequence of hazardous events[6] (Xavier, Barcellos and Freitas 2014). Material damage to the health sector's service structures and functioning is also a consequence of natural hazards (Londe et al. 2018), which limits the capacity to account for an increased number of fatalities and fulfill demands (Freitas et al 2020), with a consequent of under-reporting mortality data.

Crucial questions require answers. Which groups are fatally affected by natural hazards in Brazil? Are they distinct within the country's regions? Are the deaths influenced by the sex and age characteristics of the victims? Do they have patterns? Using a robust fatalities database allows for an appropriate assessment of extreme events impacts (Petley 2012), an analysis of the spatial distribution and temporal evolution of fatalities (Pereira et al. 2016), and the sociodemographic characteristics of the victims and circumstances surrounding fatalities. The knowledge on income disparities, class, level of literacy, cultural references, health, disabilities, gender, and other characteristics are central to comprehending social vulnerabilities to manage the multiple threats (Fordham 2013).

This study aims to assess human loss of life due to extreme weather events that occurred in Brazil by analyzing a documented mortality dataset, from 1979 to 2019, from the Brazilian Ministry of Health. By using this database, this study examined the fatalities distribution in the national territory, their periodicity, and the size and characteristics of the affected victims. It aims to recognize and make public the knowledge of different natural hazards' impacts on communities and societies, specially people and their livelihoods. Additionally, the study contributes to the understanding of the populations at risk in disasters in Brazil (Alvalá et al. 2019) and helps official governmental structures to reduce human fatalities and impacts due to natural hazards.

[3] For more information, access https://www.gov.br/saude/pt-br/composicao/svs/sistemas-de-informacao/sistema-de-informacoes-sobre-mortalidade-sim

[4] Today, the name of this entity is the Center of Studies and Research on Engineering and Civil Defense. For more information, see https://www.ceped.ufsc.br

[5] For more information, access www.emdat.be

[6] A hazardous event is qualified as "The manifestation of a hazard in a particular place during a particular period" Source: UNDRR Terminology https://www.undrr.org/terminology

Data

2.1 Mortality Information System

The Brazilian Mortality Information System (SIM) was established in 1975; its objective is collecting, registering, and disseminating quantitative and qualitative data on mortality in Brazil. SIM was created by the Brazilian Ministry of Health by following the standards of the International Classification of Diseases (ICD) of the World Health Organization (WHO). According to the WHO, the ICD is an essential tool that allows the world to report and compare data mortality in a standardized manner, supporting evidence-based decision-making.

This Brazilian system is filled out with microdata reported on death certificates, which occur at a local scale, where causes of death are certified by a physician or medical examiner, along with up to 20 contributing causes, e.g. age, sex, residence city of the deceased, and date of death. These data are classified according to a standard set of codes: deaths from 1979 through 1995 are classified using the Ninth Revision of ICD - ICD-9 (WHO 1977), and deaths for 1996 and beyond are classified using the Tenth Revision (ICD-10) (WHO 2010).

2.2 Fatalities associated with forces of nature

Data for this study was extracted from the Brazilian SIM. The Ninth Revision - ICD-9 (from 1979 to 1995) provided information on the probable cause of death of Accidents Due To Natural And Environmental Factors. The Tenth Revision - ICD-10 (from 1996 to 2019) presented data classified as Exposure to Forces of Nature. Both data are presented in Table 1.

Table 1 describes the hazards from the Brazilian fatalities database[7] that are contained in the analysis. The information follows the codes associated with the Ninth and Tenth Revisions and phenomena included and excluded in each category.

Table 1 ICD-9 and ICD-10 codes for deaths associated with natural hazards used in the analysis.

Forces of nature	ICD-9 codes (1979 to 1995)	IDC- 10 codes (1996 to 2019)	Include	Exclude
Lightning	E907 Accident due to lightning	X33 Victim of lightning	* Lightning	* Fire caused by lightning * Injury from a fallen tree or other object caused by lightning
Extreme Heat	E900 Accident caused by excessive heat	X30 Exposure to excessive natural heat (NOS)	* Excessive heat due to weather conditions * Excessive heat not otherwise specified	* Excessive heat of man-made origin
Extreme Cold	E901 Accident due to excessive cold	X31 Exposure to excessive natural cold	* Excessive cold due to weather conditions * Excessive cold not otherwise specified	* Excessive cold of man-made origin * Contact with or inhalation of dry ice or liquified gas
Storms and Floods	E908 Cataclysmic storms and floods	X37 Victim of cataclysmic storm	* Torrential rain, cyclone, hurricane, tornado, others	* Tsunami * Dam collapse or man-made structure causing earth movement
		X38 Victim of flood	* Floods caused by direct of a remote storm, high water, others	* Dam collapse or man-made structure causing a tidal wave
Earth Movement	E909 Cataclysmic earth surface movements and eruptions	X34 Victim of earthquake	* Cataclysmic earth movement caused by an earthquake and other earthquake effects * Tsunami	
		X36 Victim of avalanche, landslide, and other earth movements	* Mudslide of cataclysmic nature * Collapse of a dam or man-made structure causing earth movement	* Earthquake * Collision with avalanche and landslide not in motion

Both International Classifications, ICD-9 and ICD-10, only consider primary data fatalities that are a direct result of a hazardous event and include accidents of man-made origin, specially dam collapse, although the main cause is not associated with a natural cause (Glickamn, Golding and Silverman 1992).

All data from 1979 to 2019 contain eight variables of each fatality: natural hazard, death city, birth date, date of fatality, sex, age, locus of occurrence, and marital status (Figure 1). As a result, all categories can either have “Other," which represents "none of the options,” or “No info” and "Ignored," which are “not known information.” The

"NA," the non-applicable variable, represents "no data value stored" and/or "improperly or mistakes information" and was excluded from the analysis.

[7] Deaths due to volcano activity are presented in the database (0.02%) but are considered a problem of data registration.

Methods

The analysis of fatalities related to natural hazards in Brazil, from 1979 to 2019, was conducted using two steps. The first step was as follows:

1. Separate by cause of natural hazard: (i) lightning, (ii) excessive heat, (iii) excessive cold, (iv) storms and floods events, and (v) to earth movement;

The second step of the analysis was performed by joining storms and floods and earth movements into a single "Hydrogeological" variable. It considers that in Brazil, many of the mass movements, mainly wet mass, are a direct result of frequent and intense rains (OPAS 2015) and that most fatal landslides are rainfall-triggered (Froud & Petley, 2018).

2. Grouped by the category of natural hazard as (a) extreme temperatures- excessive natural heat and cold, and (b) hydrogeological, associated with storms and floods and to earth movements.

The data analysis is based on a crude assessment of data fatalities due to natural hazards from 1979 to 2019. The central category of analysis is the cause of fatality. Causes i.e. exposure to sunlight and other unspecified forces of nature were not considered in this analysis, as neither sequelae nor other and unspecified effects of external causes of fatalities.

Fatalities associated with dam collapse were considered in the analysis as an earth movement cause of fatality. These events of dam collapse are not associated with a natural cause but with a technological failure and are classified by using the Mortality Information System as earth movement.

The analysis was conducted based on the principles of Exploratory Data Analysis (Wickhan and Grolemund, 2016) and used the R Studio[8] program for Data Science Analysis, enabling the conversion of mortality data into knowledge.

[8] For more information, access https://r4ds.had.co.nz/index.html

Brazilian Mortality, 1979–2019

4.1 By cause of natural hazards and dam collapse

An analysis was conducted of data mortality due to natural hazards reports on 8990 fatalities in Brazil from 1979 to 2019. Lightning is the natural hazard that kills the most people in Brazil (56%), followed by earth movements (23%), and due to storms (15.4%). For Brazilian fatalities, extreme temperatures represent 5.6% of the total deaths, caused by excessive cold (3.9%) and excessive heat (1.7%) (Figure 2).

Brazilian lightning fatalities represent the deadliest natural hazard in Brazil. This phenomenon follows the global pattern in which fatalities due to lightning in lesser-developed countries are associated with working conditions in non-safe lightning structures (Holle 2016; Cardoso et al. 2014).

Despite the increase in the frequency and density (flashes km^{-2} $year^{-1}$) of lightning events in Brazil (Santos 2017; Pinto Jr., Pinto and Naccarato 2007), a slow reduction in the number of lightning fatalities from 1979 to 2019 (Table 2) occurs similarly to other nations (Holle 2016) and is possibly associated with urbanization and the expansion of individuals spending their time inside lightning-safe structures (Badoux 2016). This reduction of fatalities can also be associated with the improvement in medical care, and emergency communication and transportation (Ashley and Ashley 2018).

Table 2 Raw number and number of fatalities per year and decade due to natural hazards in Brazil, 1979–2019.

Natural hazards	**Fatalities per category**		**Per decade**			
	Raw number	**Per year**	**1979 - 1989**	**1990 - 1999**	**2000 - 2009**	**2010 - 2019**
Lightning	5035	126	1631	1499	1183	722
Earth Movement	2079	52	181	227	588	1083
Storms and Floods	1371	34	75	122	134	1040
Cold	354	9	92	73	97	92
Heat	151	4	49	30	44	28
TOTAL	**8990**		**2028**	**1951**	**2046**	**2965**

Despite the increase in the average annual temperature from 1961 to 2018 in Brazil (RAMOS et al. 2018) and heat waves that affected Brazil as a whole since 2005 (NOBRE et al. 2018), the analysis developed indicates that only 1.67% of the total fatalities are due to exposure to excessive natural heat.

Excessive natural heat, classified as a heatwave[9], is as a silent mortal natural hazard and a leading killer[10] among natural hazards (IFRC 2020; Poumadere et al. 2005). It has a direct impact on mortality, but the reported deaths can be difficult to establish, and how to estimate how heat exposure exacerbates other preexisting health conditions (WMO & WHO 2015; Hajat and Kosalky 2010).

Brazilian studies have demonstrated the direct association between temperature rise and the intensification of heat stress conditions (Bitencourt et al. 2021); mortality due to the increase in vector-borne, water-borne, and food-borne diseases; and cardiovascular and respiratory diseases (Hacon, Oliveira and Silveira 2018). All these mortality data are not qualified as a direct impact of extreme heat and represent a plausible explanation for why the number of fatalities due to exposure to excessive natural heat is so low. There is either the hypothesis that populations in warm climates are adapted to high temperature (Son et al. 2016) and there is a possible adaptive response to a hot environment ("acclimatization") in which an individual “learns” to better tolerate exposure to excessive heat (WMO & WHO 2015). For Brazil, there is no scientific evidence suggesting the human adaptation to temperature variation exposure and adverse health outcomes to temperature change under climate change scenarios (Zhao et al. 2018; Guo et al. 2018)

Events associated with earth movement are those that present irregular and increasing patterns of mortality (Figure 3), and don´t present pattern until 1995, when the number of fatalities per year increases and becomes the category of the natural hazard that kills the most people.

Storm fatalities, associated with floods and cataclysmic events, gradually increase from approximately 2000 to 2019 (Figure 3). An increment occurs due to a single and catastrophic outlier dot: the 2011 Serrana Region tragedy, a single event characterized by 24 hours of torrential rain on January 11 and 12, 2011, that affected the cities of Petrópolis, Teresópolis, Nova Friburgo, São José do Vale do Rio Preto, Areal, and Bom Jardim, in the Serrana Region of the state of Rio de Janeiro, which is considered the most serious disaster event in Brazil[11] (Marengo and Alves 2012; BANCO MUNDIAL 2012; Coates 2017; Dourado et al. 2013).

The World Meteorological Organization (2021) diagnoses flash floods, riverine floods, and general landslides as major responsible for natural hazards fatalities in Latin America. Extreme rainfall is recognized as the leading trigger of landslides (Froud and Petley 2018) and floods (Doccy et al. 2013), and the rising mortality trend is a result of high intensity storms associated with rainfall seasons (Petley 2012).

The gradual and continuous rising trend observed in the data analyses reveals the role that storms and earth movement play in increasing fatalities in Brazil from 1979 until 2019 (Figure 4).

A deeper analysis indicates that years that have peaks of fatalities (2008, 2010, 2011, and 2019) are associated with the passage of high intensity rain in specific regions and with structural failures of dams (Figure 5).

Is possible to note at Figure 4 and Figure 5 that Mariana' dam collapse, developed in November, 2015, hasn't made too much impact on the number of fatalities associated with Earth movement as Brumadinho' tragedy in January, 2019 that killed approximately 250 people.

4.2 By date of occurrence

The monthly distribution of fatalities registered in Brazil from 1979 to 2019 indicates January as the month with a disproportionately high number of fatalities due to natural hazards. Hydrogeological processes (64.7%) and lightning (34.5%) are the most responsible events for the high number of deaths[12].

The month with lowest number of fatalities is August, in which extreme temperatures increase in relevance, namely, 16.2% of total deaths. During July, extreme temperatures become the most responsible for fatalities (43.6%), followed by hydrogeological processes (30.3%). Lightning events reach the smallest number of fatalities in July (Figure 6) because of July is the peak of the dry season, and is characterized by fewest lightning strikes.

The seasonality analysis of fatalities displayed in Figure 6 also presents the period from December to March (Southern Hemisphere (SH) Summer) with the highest percentage of fatalities. For that period, hydrogeological hazards (48%) show an almost equal number of fatalities as lightning (50%). The period of April to June (SH autumn) hydrogeological events are responsible for higher number of fatalities (47%) than lightning and (40%).

In Brazil, the different seasonal distribution of precipitation varies along the region and period of the year, varying from wet to dry conditions. The SH summer is the season with the most significant rainfall in the Southeast region. It is characterized by isolated heavy rains (high intensity with a short duration; CEMADEN 2019), and the main characteristic is the occurrence of rains for several days[13] (CEPTEC 2021). The SH autumn is the rainiest period in the Northeast region and, despite being mainly characterized by a dry climate (Marengo, Torres and Alves 2017), is when extreme precipitation occurs and when the highest number of fatalities due to extreme precipitation is concentrated. Each region has particularities in fatalities, and they are presented at Figure 7.

4.3 In the national territory

The analysis of fatalities due to the natural hazards categories in the Brazilian territory shows a predominance of fatalities in the Southeast (49.3%). The South concentrates 19.5% of fatalities; the Central-West, 12.7%; the Northeast, 10%; and the North region has the lowest percentage (8.5%).

In almost all Brazilian regions, lightning is the deadliest hazard; an exception is in the Southeast, where hydrogeological processes are responsible for more than half of fatalities (Table 3). In the Central-West, the number of fatalities associated with lightning events is disproportionally higher than the highest death rates per year[14] (Cardoso 2014).

Table 3 Percentage of the number of each group of categories in regions of Brazil; North (N), Northeast (NE), South (S), Southeast (SE), and Central-West (CO).

Hazards	N	NE	S	SE	CO
Lightning	79%	49.6%	66.8%	41.5%	85.2%
Hydrogeological	19%	45.8%	20.1%	54.8%	10%
Extreme Temperatures	2%	4.6%	13.1%	3.7%	4.8%

Fatalities associated with hydrogeological events occur predominantly in the Southeast: ranked first is the state of Rio de Janeiro, followed by Minas Gerais (MG), and São Paulo (SP) states. Accordantly to Froud and Petley (2018) the number of fatalities is strongly related to seasonal rainfall regimes, but other studies demonstrate that the spatial distribution of fatalities is not exclusively linked with rainy regimes.

In Portugal, the principal mortality hotspot is related to high population numbers and natural conditions (Pereira et al. 2016). In the United States, the spatial distribution of flood fatalities is also linked with heavily populated urban centers and steep topographical relief (Ashley and Ashley 2008). They are also associated with individuals' behavior: fatalities are aggravated by deliberate decisions regarding risk-taking, which may vary by sex, age, and circumstances (Zagheny, Muttarak, and Striessnig 2015; Doccy et al. 2013).

In Brazil, often the most affected regions are those with the greatest population density, and the poor quality of urban infrastructure services is associated with intense rainfall regimes (Peres et al. 2020). The Southeast, in which most of Brazil's population is concentrated[15], is where the majority of hydrogeological fatalities are concentrated.

The states of Santa Catarina (SC) in the South region and Pernambuco in the Northeast, occupy the fourth and fifth positions, respectively. The state of Pará, in the North region, is in the sixth position, with a high number of hydrogeological fatalities due to landslides (Figure 9). The sixth position of Pará State is due to landslides in the Itaituba municipality[16], recorded since 2006. A very brief data analysis of Itaituba' fatalities indicate that 63% of the fatal victims are gold miners and all of them males.

Lightning fatalities are concentrated in the states as follows: in the Southeast region, SP and MG; in the South region, Paraná (PR) and Rio Grande do Sul (RS); and in the Central-West region, Goiás and Mato Grosso do Sul

(MS). Those six states are responsible for 66.5% of all fatalities associated with lightning in Brazil from 1979 to 2019, and are associated with open space labor activities and is related to a high percentage of the population being involved in rural activities (Cardoso et al. 2014)

The states of PR, SC, and RS are in the South. They have the most fatalities associated with extreme temperatures, mostly associated with extreme cold events. SP, MG, and MS represent 81.7% of Brazilian's total fatalities associated with extreme temperatures.

Brazil is also affected by extreme droughts related to extremely hot temperatures and the distribution of rainfall. The Amazon region presents a natural climate variability, producing droughts and floods (Marengo and Espinoza 2016); however, recently, it is presenting changes in its rainfall conditions (Perez et al. 2020), experiencing two extreme dry spells (2005 and 2010 droughts) and three floods, in 2009, 2012 and, 2021 (Espinoza et al. 2022; Satyamurti et al. 2013; Marengo et al. 2011). The Northeast have been the most affected by high intense droughts from, at least, 2000 (Cunha et al. 2019; Cuartas et al. 2022); but no fatalities were associated with these high intense droughts in the database.

4.4 Multidimensional identities of fatal victims and circumstances of death in Brazil

On average, 78 million cloud-to-ground lightning strikes occur in Brazil per year. The majority of fatalities due to lighting occurs in rural areas (26%), followed by those inside a home (21%), in which the victim is on the phone, next to electric equipment, and/or close to windows and doors (Cardoso et al. 2014). More than three-quarters of fatal victims are males (82%), and the most affected group is aged from 20 to 29 years. The fatal victims aged less than 10 years and older than 70 years are few, representing 4% and 2%, respectively, in Brazil (ELAT 2019).

4.4.1 Sex[17] and age[18] analysis

When focusing on fatalities associated with extreme temperatures and hydrogeological hazards in Brazil, males account for 65% of fatal victims. Comparatively, male victims are the majority within every age group; female victims from infant to teen (0–19 years old) have an equivalent number of fatal victims for each age group, and male victims have the same pattern (Figure 10).

In the female group, the most fatally affected are under 20 years old, representing 37% of the total female victims of natural hazards events in Brazil from 1979 to 2019. The female newborns, infants, and toddlers (under 5 years old) have the highest number of fatalities. The group comprising females aged up to 75 years accounts for 3.3%.

For the male victims, the group aged over 30 and under 50 years represents 37% of the total male fatal victims; those among 40 and 44 had the highest number of fatalities. Similar to the female victims, the group aged up to 75 years represents 3% of the total victims (Figure 11).

Analysis by age and category of natural hazards indicates that males have been much more fatally affected than females in all ages categories, except for victims aged over 80 years old, the number of female victims affected by hydrogeological is higher than that for males over 80 years old.

Are these characteristics of the Brazilian fatal victims of natural hazards consistent with the literature's findings?

Based on sex mortality outcomes, some authors support the hypothesis that in certain types of disasters, females and males have a different propensity toward risk-taking. Many studies have associated the level of country income with the physical and behavioral characteristics of the victims and their exposures to natural hazards. For high-income countries like Italy (Salvati et al. 2018), Greece (Diakakis and Deligiannakis 2017), and Australia (Coates 1999), the higher number of males fatalities is justified by their propensity toward risk-taking, due to their risky behaviors. Alternatively, from another perspective, the higher risk perception of Swiss women is what leads them to exhibit more cautious and less adventurous behavior than men (Badoux et al. 2016).

Another perspective in the literature has attempted to understand the social processes of gender inequalities and indicates that social norms and role behaviors, potentialized by socioeconomic status, are responsible for differences in the number of male and female fatalities due to natural hazards (Neumayer and Plümper 2017).

4.4.2 Locus of fatality

The majority of fatal victims in Brazil die at home (40%), and 15% die in a hospital. When desegregated by sex, locus of fatality, age, and category of natural hazards, the majority of female fatal victims affected by extreme temperatures (53.4%) die in a hospital, and newborns, infants, and toddlers (under 5 years old) die the most. Adult males are likely to perish in a public place, and the adolescents and the elderly[19] groups, in a hospital and at home (Figure 12)

When affected by a hydrogeological hazard, the majority of female victims die at home (56%), independently of their age. 35% of male fatal victims also die at home, but the majority of adults male's locus of fatality are qualified as "other," which indicates that they did not die at home, a public place, or at the hospital.

In Mexico, the risk of dying is associated with a sex division of labor, with men's work regularly occurring in open spaces (Jauregui-Dias et al. 2019). In India, a higher proportion of males than females participate in the labor force, and most work is performed outdoors (Mahapatra et al. 2018). Fiji´s worst natural disaster, the 1931 hurricane and flood, suggests cultural norms imposed differently on men and women are the main element that determined the distinctive patterns of fatalities (Yeo and Blong 2010). In South Korea, female death occurs mostly in residential areas, whereas for males, it occurs manly outdoors (Myung and Jung 2011).

The age and locus of fatalities have also been a focus of research and are generally attributed based on the overrepresentation of the ages and their capacities. The high mortality among elderly individuals and young children is associated with their lack of physical strength and capacities (Bern et al. 1993; Coates 1999; Poumadere et al. 2005; Thacker et al. 2008; Yeo and Blong 2010; Doocy et al. 2013) or awareness (Sanchez et al 2009)

4.4.3 Marital status analysis[20]

From those whose marital status was registered[21], the majority of fatally affected victims were single (47%). Married victims represent 40%of the total and separated victims and widow represent 5% each one. The marital statuses of 3% of the total victims were ignored (Figure 13a).

When the marital status is analyzed in conjunction with sex data, the same pattern of marital status of the victims can be found inside each group; single male represent 48% of the total male victims and 45% were single female victims. However, married men die more than married women and widow fatalities are higher inside the female group (Figure 13b)

The analysis desegregated by marital status, sex, and category of natural hazards generates a notable and singular finding. Extreme temperature affects much lesser the female group than their male counterparts. However widow number of fatalities of the elderly female victims is higher than the elderly male group, despite the number of male victims to be bigger on both categories of natural hazards (Figure 14)

Our study reveals that in Brazil, males are the majority of fatal victims due to natural hazards. The female youth group (aged under 20 years) and female babies and infants are more affected than their male counterparts. Elderly individuals of both sexes account for a small percentage of the total. Single males and females represent more than half of the victims, but female widows are highly affected. The majority of the fatal victims die at home, and "other" is the locus category where male victims affected by hydrogeological events die the most.

Life inequalities in Brazil distinguish male and female social roles in society, but despite of it, there has been an increase in the number of female-headed households, the educational level of women, and women's labor market participation (Cavenaghi & Alves 2018). However, women continue to earn lower incomes[22] and are less economically active than Brazilian men (IBGE 2014).

Further research is necessary to understand these findings.

[9] According to the World Health Organization and World Meteorological Organization, "there is no universally accepted definition for heatwave but they are understood to be periods of unusually hot and dry or hot and humid weather that have a subtle onset and cessation, a duration of at least two or three days, usually with a discernible impact on human and natural systems" (WMO & WHO 2015)

[10] Tens of thousands of deaths due to heatwaves, over the last three decades, have been reported; India in 1998, Pakistan in 1995 Chicago, the United States in 1995. In other regions especially Mexico (April 1990) and Australia (1993, 1994, 1995, and 2009). Across Europe in July and August 2003 and the Russian Federation in July and August 2010 (WMO & WHO 2015).

[11] According to the INPE (National Institute of Space Research), the INMET (National Meteorological Institute) Station registered 166 mm of rainfall in Nova Friburgo in two days, more than 70% of the average historical value for the month. (BANCO MUNDIAL 2012)

[12] Notably, the collapse of the Brumadinho dam was not associated with natural hazards and contributed to January having the most fatalities.

[13] The SH summer in the Southeast region can be either characterized by the occurrence of long aestival periods with drought lasting from 7 to 15 days.

[14] Annual death rates are the average probability of a person being struck by lightning and dying (CARDOSO 2014)

[15] In 2015, the Southeast was the region in which most Brazilians lived (41.9%), followed by Northeast (27.6%), South (14.3%), North (8.6%), and Central-West (7.6%) (IBGE 2016)

[16] Itaituba is a municipality in the State of Pará. It is located on the left bank of Tapajós River. Its population in 2010 was 97.343 inhabitants. The highlights in the economy are the industrial sector, mining, and agriculture. In the mining sector, gold exploration activities stand out (Source: www. itaituba.pa.gov.br)

[17] Sex analysis is associated with whether the victim was born male or female.

[18] In Brazil, the child group ("crianças" in Portuguese) includes the group from 0 to 12 years old; adolescents are aged from 12 to 18 years (ESTATUTO DA CRIANÇA E DO ADOLESCENTE, LEI Nº 8.069/1990). The youth is the group from 15 to 29 years old (PLANO NACIONAL DA JUVENTUDE, LEI Nº 4530/04). The adults from 30 to 59 years old and the elderly equal and above 60 years old (ESTATUTO DO IDOSO, LEI Nº 10.741/2003)

[19] Please, see footnote 18

[20] Per the Brazilian Institute of Geography and Statistics (in Portuguese: Instituto Brasileiro de Geografia e Estatística; IBGE), the marital status analysis is on individuals aged 15 years and older.

[21] Notably, 18.2% of the marital data were not available.

[22] Income inequalities in Brazil are prominent in accordance to race and color; the Black and the mixed populations represent 3/4 of the Brazilian population and have the lowest income (IBGE 2016).

Natural Hazards, Brazilian Disasters, And Climate Change

Natural hazards are induced by natural phenomena and occur daily. Are multi-category and affect the population and territory differently over time causing losses and damage. They are recognized as leading triggers that increase and worsen the preexisting socioeconomic conditions of vulnerable communities and provoke disasters (Hummel, Cutter and Emrich 2016).

In Brazil, approximately 85% of disasters are related to too much or too little rainfall. Growth in the number of occurrences of disasters has occurred, either due to the intensification of natural hazards or the increase in vulnerable regions exposed to weather extremes (Alvalá and Barbieri 2017). Southern Brazil is the region most exposed and vulnerable to disasters triggered by extreme rainfall (Marengo 2021), and the Northeast is most affected by too little rainfall (Cunha et al. 2019).

Droughts are widespread throughout the Brazilian territory, causing a conjunct of enormous impacts, affecting more people than any other natural hazard (Marengo, Torres and Alvez 2017) and provoking the highest impacts on economic and social structures in Brazil (Cunha et al. 2019). Droughts generate, as the first stage, a reduction in water supply, affecting agriculture, industry, and energy generation (Nobre et al. 2016) and health care facilities, schools, and other essential services (Freitas et al. 2020). The impacts on human health are also multiple and extend to the medium and long term, worsening existing diseases and facilitating the development of new diseases (OPAS 2015).

The herein-developed analysis of natural hazards fatalities in Brazil from 1979 to 2019 identifies the many fatalities associated with an excess of water due to storms, floods, and landslides triggered by heavy rain. A deeper analysis shows that the sudden increment of fatalities (2008, 2010, 2011, and 2019) often concentrated around large-scale disasters[23]. Table 5 presents a list of selected[24] Brazilian disasters from 2008 to 2019 and their characteristics: the per disaster number of fatalities and the number of displaced and homeless victims.

Table 5 List of selected Brazilian disasters, from 2008 to 2018, with the number of deaths, and displaced and homeless victims (source: Author's compilation based on Ministry of National Integration Databases).

Year	Month	State	Municipality	Category	Deaths	Displaced	Homeless	More info
2008	November	Santa Catarina	Vale do Itajaí	Landslides	92	>36K	>70K	Banco Mundial 2008
2010	January	Rio de Janeiro	Angra dos Reis	Landslides	52	652	>2K	BBC NEWS 2010
2010	April	Rio de Janeiro	Niterói and São Gonçalo	Flood and Landslides	405	>15K	>12K	BBC 2010
2010	June	Alagoas	União dos Palmares	Flood and Landslides	12	>20K	>37K	
2011	January	Rio de Janeiro	Serrana Region	Cataclysmic	889	>25K	>8K	Banco Mundial 2012
2013	March	Rio de Janeiro	Petrópolis	Landslides	34	>1K	>1K	
2015	November	Minas Gerais	Mariana	Dam Collapse	7	308	504	
2016	March	São Paulo	Francisco Morato	Landslides	8	21	>1K	
2019	January	Minas Gerais	Brumadinho	Dam Collapse	171	55	143	G1 2019

Figure 15 presents a brief analysis of data mortality, with the identities of the victims and circumstances of deaths for all disasters in Table 5. The result presents no standards on victims' profiles.

The analysis of disaster data mortality reveals that each disaster has its distinct patterns. Each disaster presents different fatal victims characteristics and can be associated, i.e. with the timing of occurrence, when individuals are usually at home sleeping, as the major influence over mortality patterns (Do Carmo and Anazawa 2014). Mortality patterns can also associated with the magnitude of the disaster, and all inhabitants are equally affected, beyond their social vulnerabilities (Cardoso 2018). The place where the disaster event occurs also affects outcomes, i.e. the Angra dos Reis disaster in which the victims were in a lodge celebrating New Year's Eve.

A comparative analysis of each disaster and Brazilian hazards fatalities from 1996 to 2019 identified similarities among the categories. For example, both technological disasters, the dam collapses in Mariana (MG) in 2015 and Brumadinho (MG) in 2019, are different from disasters associated with natural hazards. They present different patterns for age category, locus of fatality, sex, and marital status (Figure 13).

The analysis of sex data indicates that in most disaster situations, males are highly fatally affected. By contrast, the number of female mortalities in large-scale disasters worldwide is higher than that of males (UN 2018). For Cyclone Nargis (Myanmar) in 2008, female fatalities were 61% of deaths; in the 2004 Indian Ocean Tsunami in

Banda Aceh (Indonesia), 70%; and in Cyclone Gorky in Bangladesh in 1991 (UNISDR 2015), 91%. These analyses incite new questions and demonstrate the need for new research for Brazil.

In addition to the loss of life, there is the need to recognize that the severity of climate change is more than “the number of fatalities." Climate change is underway (IPCC 2012, IPCC 2021, IPCC 2022), and particularly for Brazil, extreme climatic events namely heavy rains, droughts, and floods will become intensely and frequently (Marengo 2014), and consequently, will amplify the impacts and challenges that social systems meet, especially for individuals who already experience vulnerabilities in their daily lives (Perez et al. 2020). These ongoing climatic changes can also exacerbate social inequalities and the consequences for public health, promoting the development of water-borne and vector-borne diseases, specially post-traumatic psychosocial problems and cardiovascular and respiratory diseases (Hacon, Oliveira & Silveira 2018).

[23] Disaster scales are differentiated by the required assistance they generates. Small-scale disasters affect local communities and require assistance beyond the affected community. Large-scale disasters affect society and require national or international assistance (Source: UNDRR Terminology https://www.undrr.org/terminology)

[24] Some relevant Brazilian disasters, especially the 2010 flood and landslides in Recife and Zona da Mata/Pernambuco (Northeast Region) and the 2015 landslides in Bahia (Northeast Region) are not in Table 5, because their data mortality is not identified by the Mortality Information System (SIM) of Brazil's Ministry of Health.

Data Bias

The use of secondary data requires careful consideration. The quality of the database and the quantity of registered data can vary. Qualitatively, the causes of deaths can be misjudged because of medical uncertainties; thus, what is declared on a death certificate might not be the cause of death. They can also be affected by coding errors because personnel are sometimes insufficiently qualified for this type of activity (Laurenti, Jorge and Gotlieb 2008). Multiple causes of death can be associated with weather events, but they are rarely registered as a direct result of it (Xavier, Barcelos and Freitas 2014).

Quantitatively, differences in the two classification systems of the cause of death can also be responsible for data variation. The ICD 09, used to qualify data mortality from 1979 to 1995, and the ICD10, from 1996 up to now, use a distinct standard set of codes, and this difference might be responsible for the increment in the number of data mortality of ICD10 when compared with ICD09 data (Thacker 2008).

The inconsistent differences in the amount of data within the same country may reflect what the literature calls geographical bias in the data sources (Pereira et al. 2017), that is, unsatisfactory coverage in many municipalities in the country, resulting in distortions in the proportionality of the reported causes (DATASUS/IDB 2000). This inconsistency can also be associated with the lack of skills in data collection (Petley 2012) in different regions of the country.

There is also a need to recognize and consider that the passage of extreme natural hazards can damage local health establishments or disrupt the whole health service, affecting data fatalities’ records and management

(Xavier, Barcelos and Freitas 2014)

Conclusions

Although climate change is often framed as a global problem for all humanity, the heterogeneity of its manifestations, impacts, and responses must be carefully considered (Sultana 2014). The first challenge is to identify the individuals who are fatally affected by natural hazards and the elements that result in some residents within the same community being more vulnerable and or capable to anticipate, respond, and recover from impacts than others.

The use of a systematic approach and standardized protocols for collecting and registering mortality data due to natural hazards is fundamental for improving the assessment of the diverse aspects of multi-hazards risks, making it possible to anticipate the impacts and prevent potential consequences. However, international standards do not consider local realities, and constraints may not work equally for each country. For Brazil, the classification of landslides as a geophysical event that is not associated with storms and floods may prejudice comparative studies on the global impact of water-related disasters. The detachment of the increment of extreme heat and the increment of mortality due to long-term droughts also underestimates the impact that Brazilian droughts may have on people's lives.

This study demonstrates that national patterns of natural hazards mortality in Brazil are associated with those that occur daily through the national territory and over time. That the highest number of fatalities occurs in areas of high population density with poor-quality urban infrastructure services and the sudden increment of mortality in a short period is consequence of disaster events.

Despite that singularities in each disaster situation referred to the context—the significance of the moment, place, and circumstances in which people live—and to the typology of hazards, there is a need to recognize and correlate the “fragilities” with the “capacities” of individuals, families, societies, and the socioeconomic systems to manage threats, strengthening potential resources and individuals’ knowledge, and leadership to manage threats and build resilient places for living.

In general, women are agents and leaders of collaborative change in climatic extreme scenarios (CRED-UNISDR 2015), developing strategies for and key roles in environmental management, disaster risk reduction, and climate change resilience (UN 2018).

The responsible bodies have space and opportunities to urgently implement new measures to manage threats of natural hazards, as long as the fatalities associated with forces of nature continue to occur and increase.

Declarations

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Ethics Declaration

Competing of Interest

The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are relevant to the content of this article.

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Figures

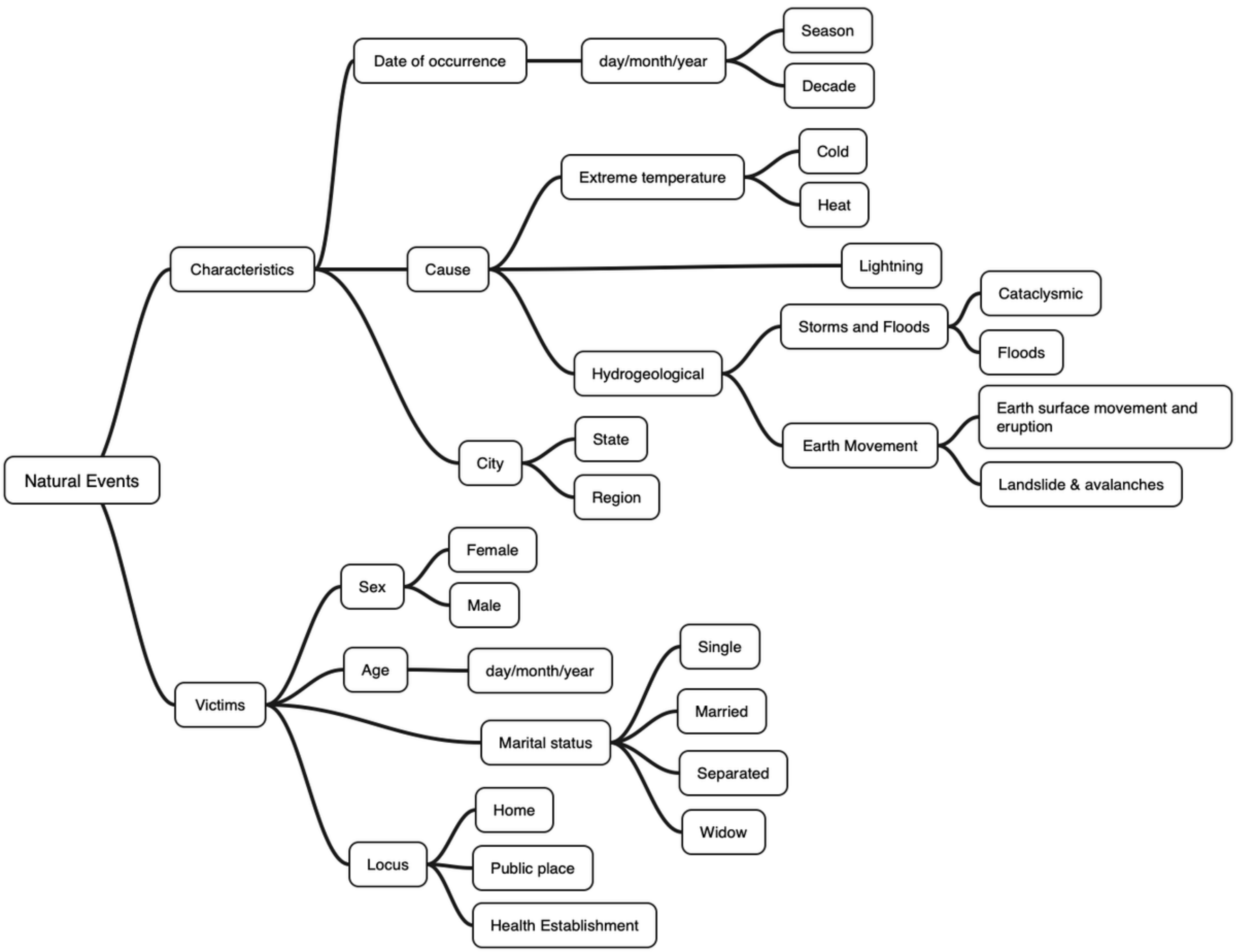

Figure 1

Flow chart of data characteristics. Variables as “other”, “no information” and “ignored" are also analyzed but not represented at the figure.

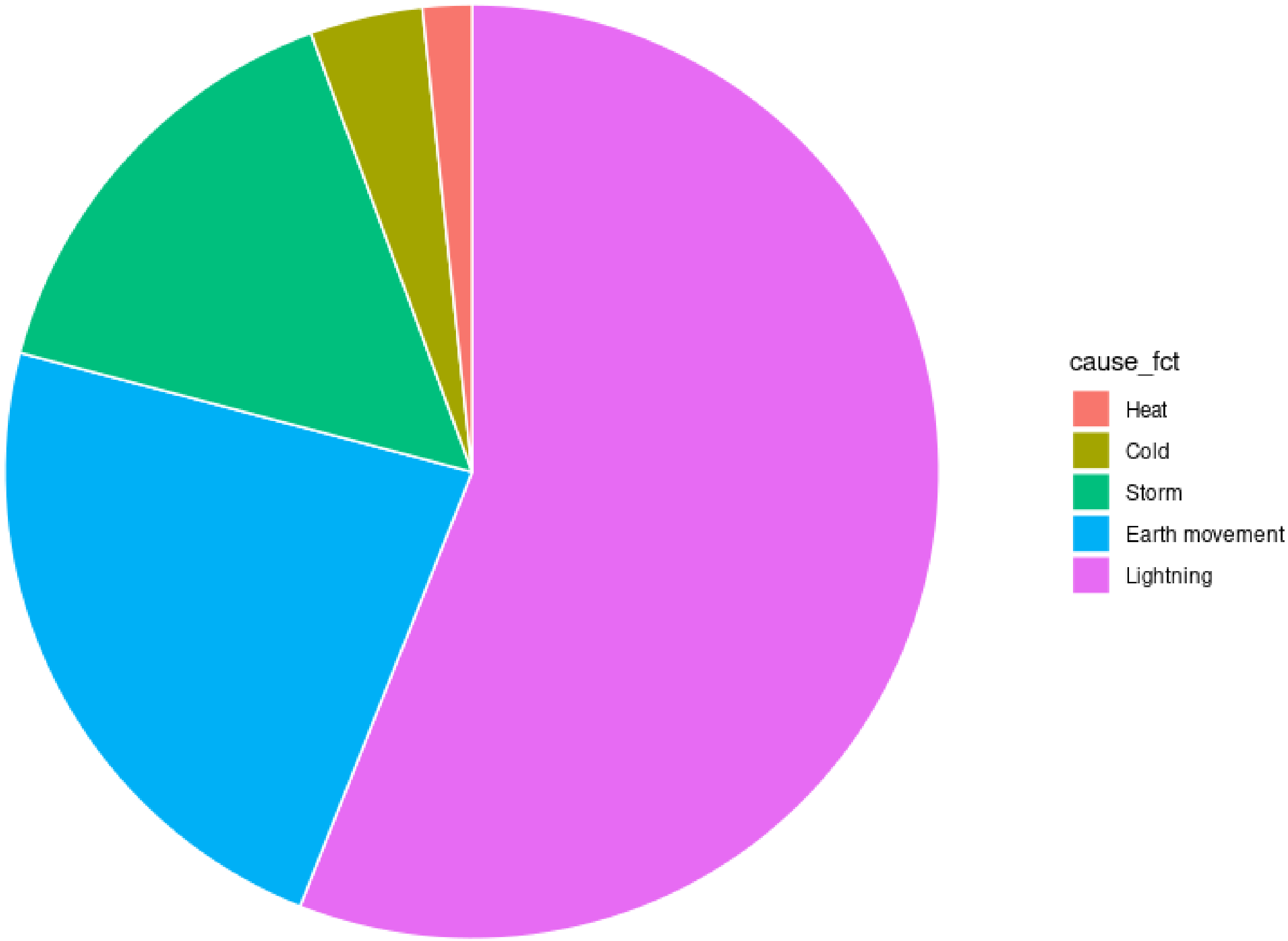

Figure 2

Natural hazard fatalities in Brazil from 1979 to 2019 by category of analysis.

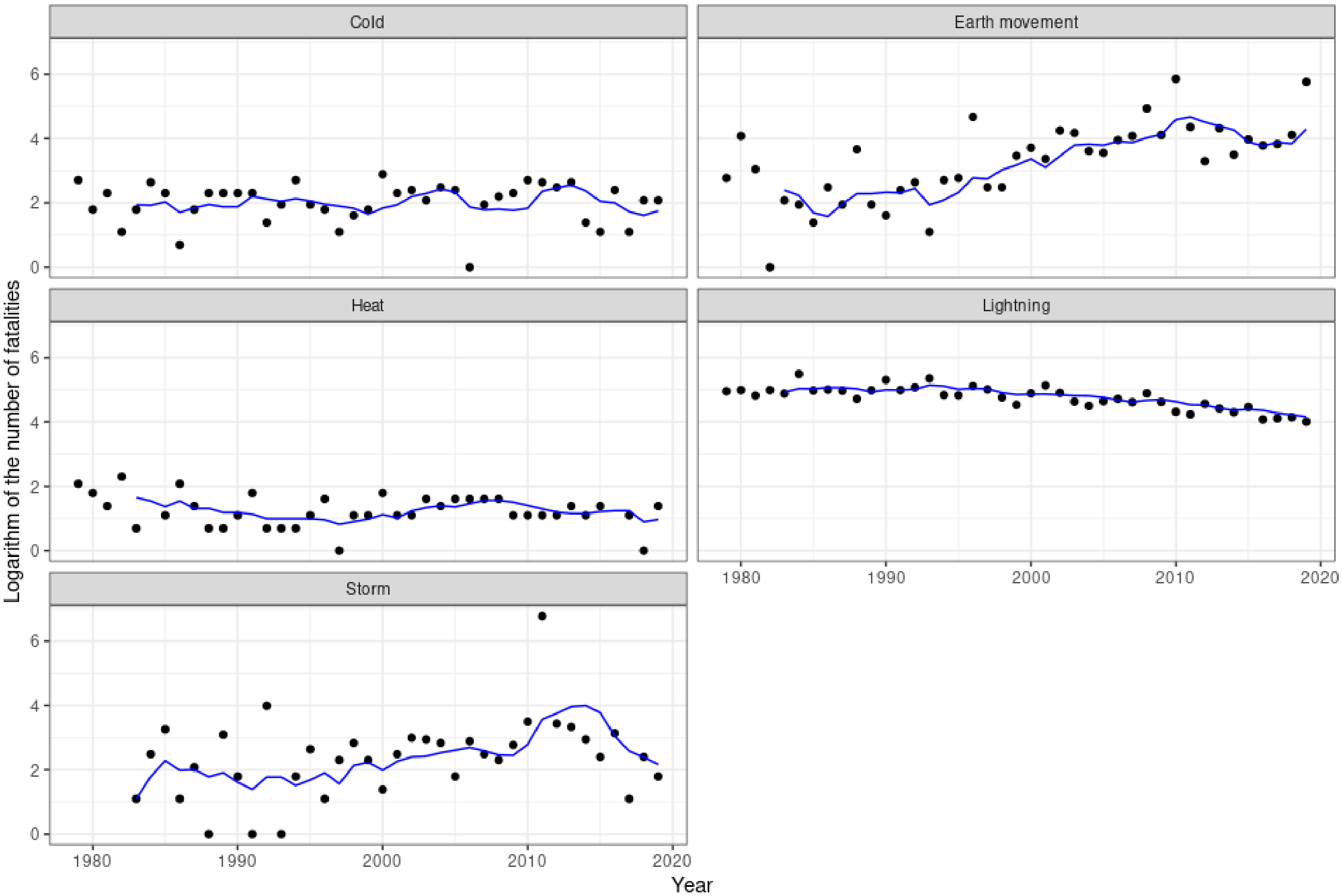

Figure 3

Logarithm number of fatalities of each category of natural hazard from 1979 to 2019 in Brazil

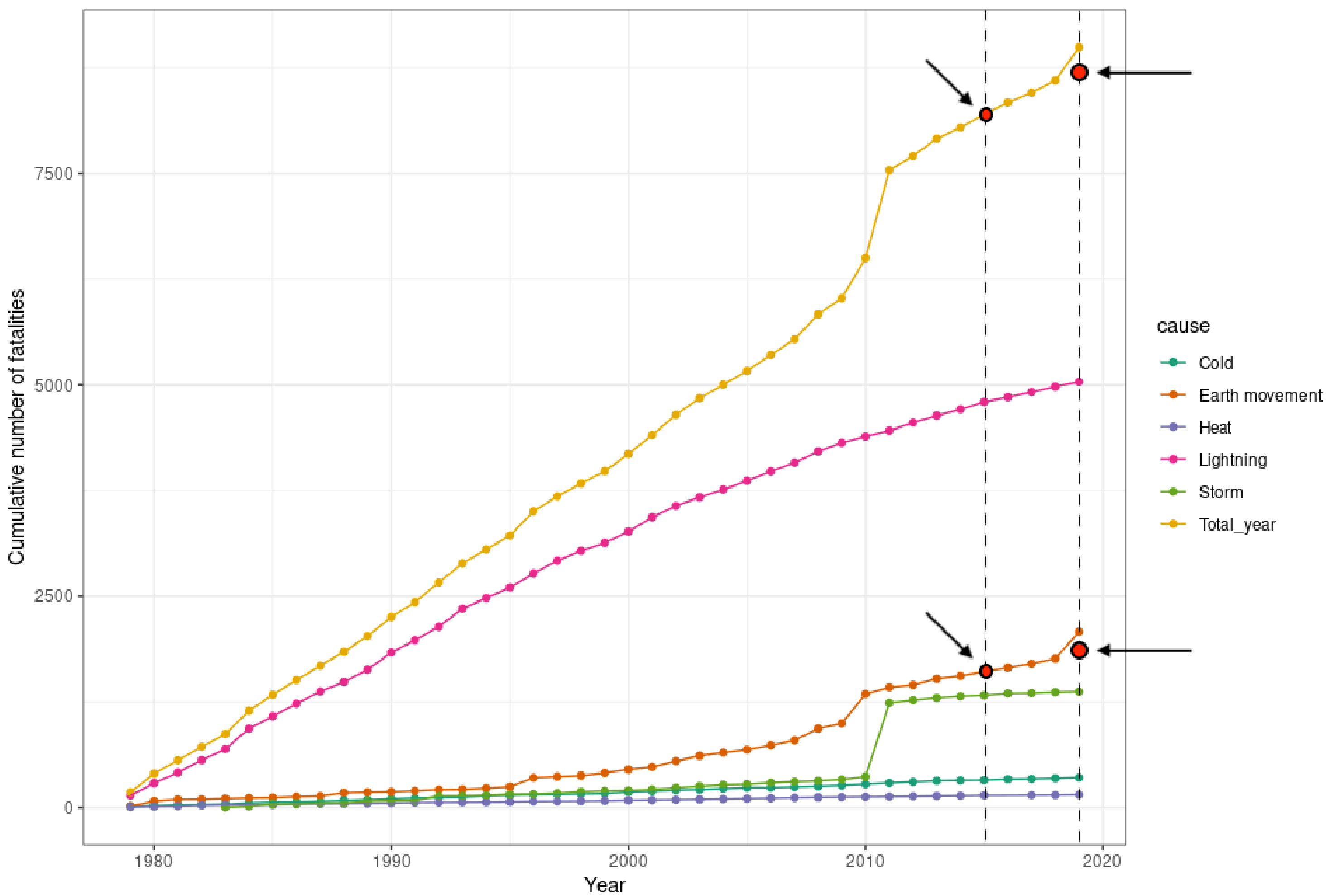

Figure 4

Graphic referred to the total cumulative number of fatalities due to different categories of natural hazards in Brazil from 1979 to 2019. The red dots, signaled by the arrows, represent the cumulative number of fatalities if fatalities due to structural failures of dams wouldn't be considered at the analysis.

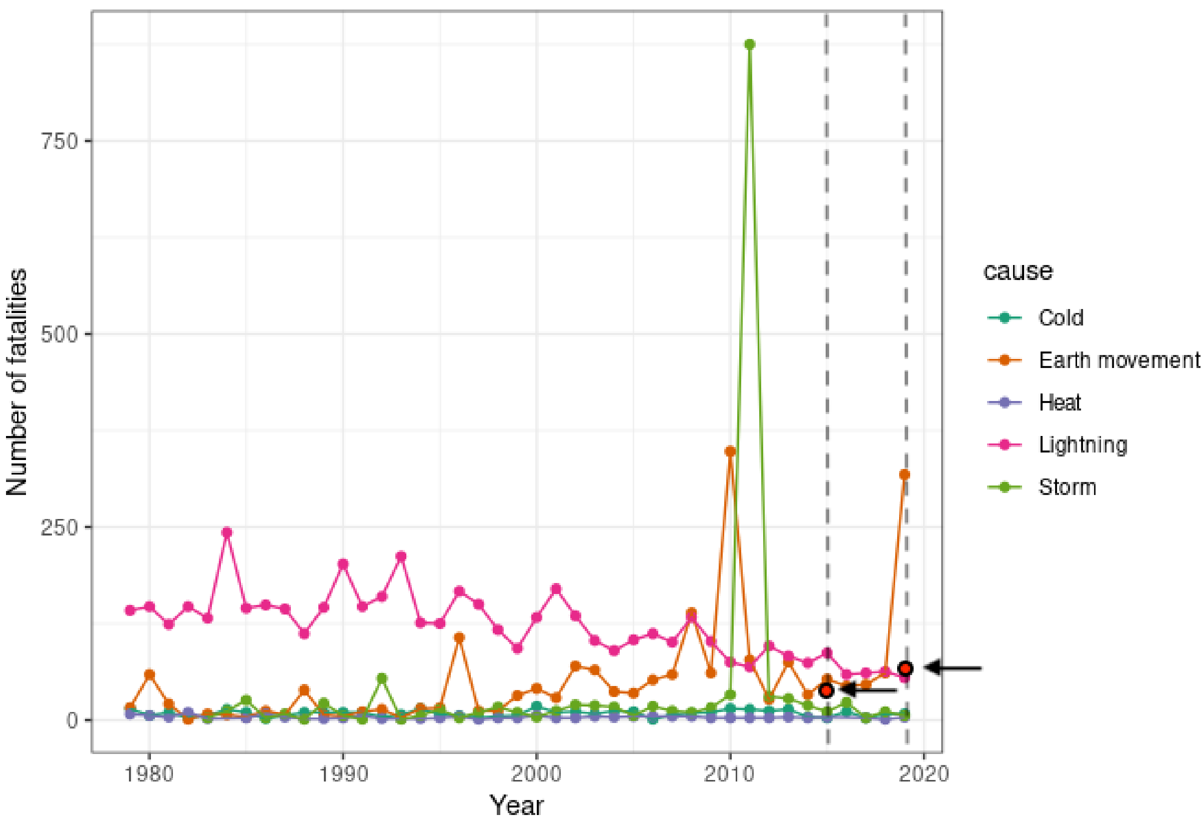

Figure 5

Graphic referred to the number of fatalities due to different natural hazards causes in Brazil from 1979 to 2019. The red dots, signaled by the arrows, represent the number of fatalities associated with Earth movement without considering structural failures of dams fatalities.

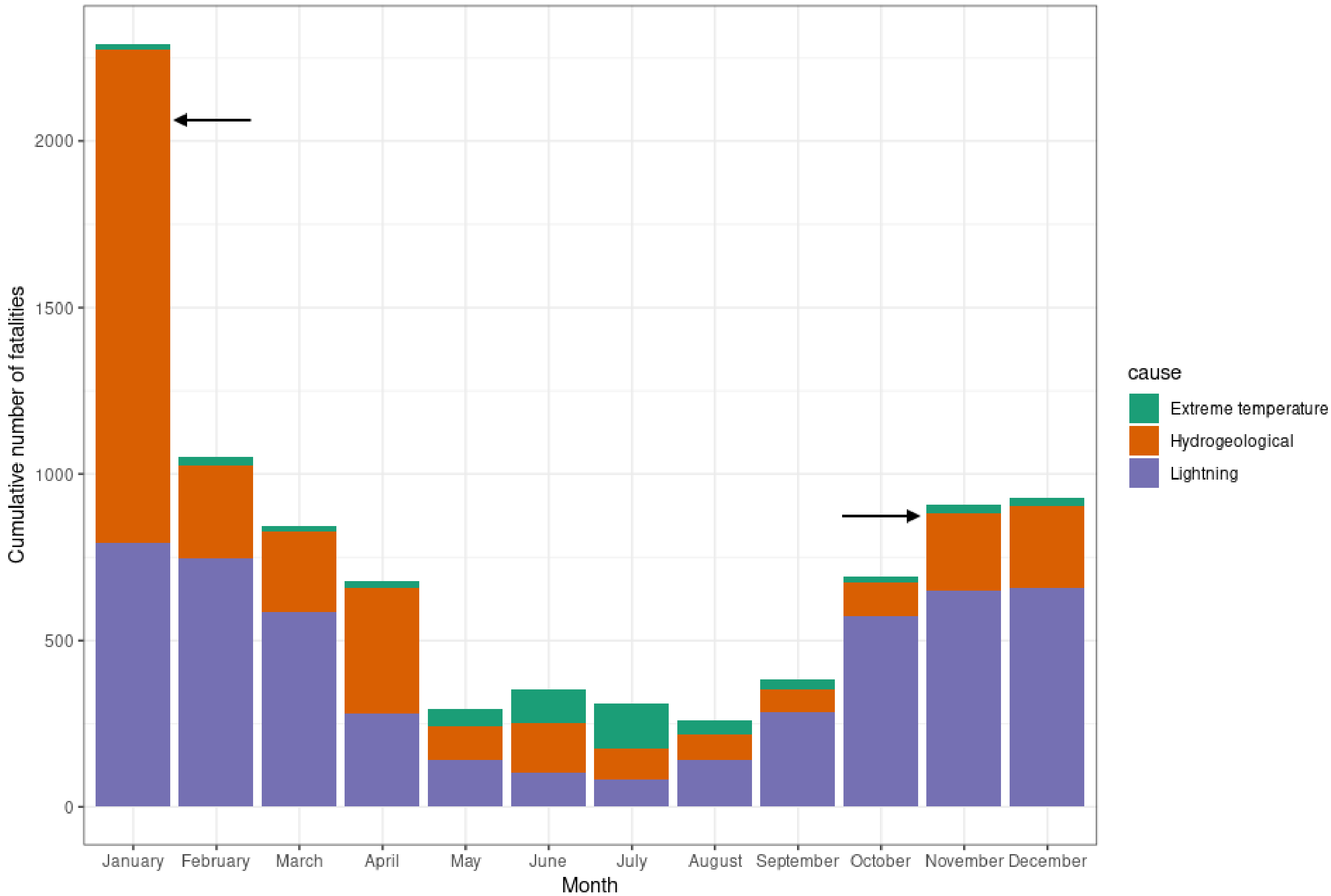

Figure 6

Monthly distribution of natural hazards fatalities (cumulative data over the studied period). Each color indicates the three grouped categories of natural hazards defined for this study. The arrows represent the number of cumulative fatalities in January and November without dam collapse fatalities.

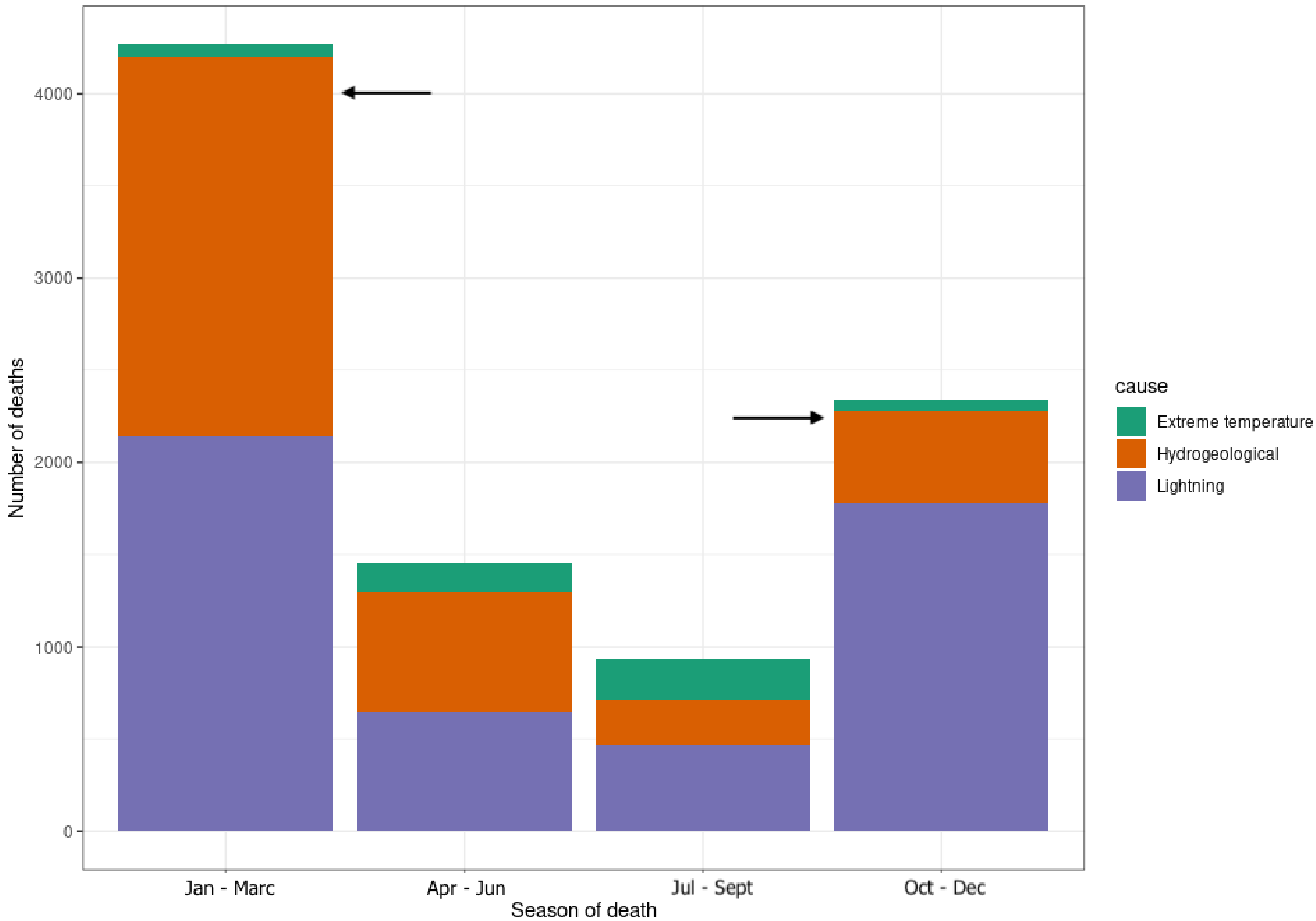

Figure 7

Cumulative distribution of national hazards fatalities of each grouped category by season. The arrows represent the number of cumulative fatalities in each period, without dam collapse fatalities.

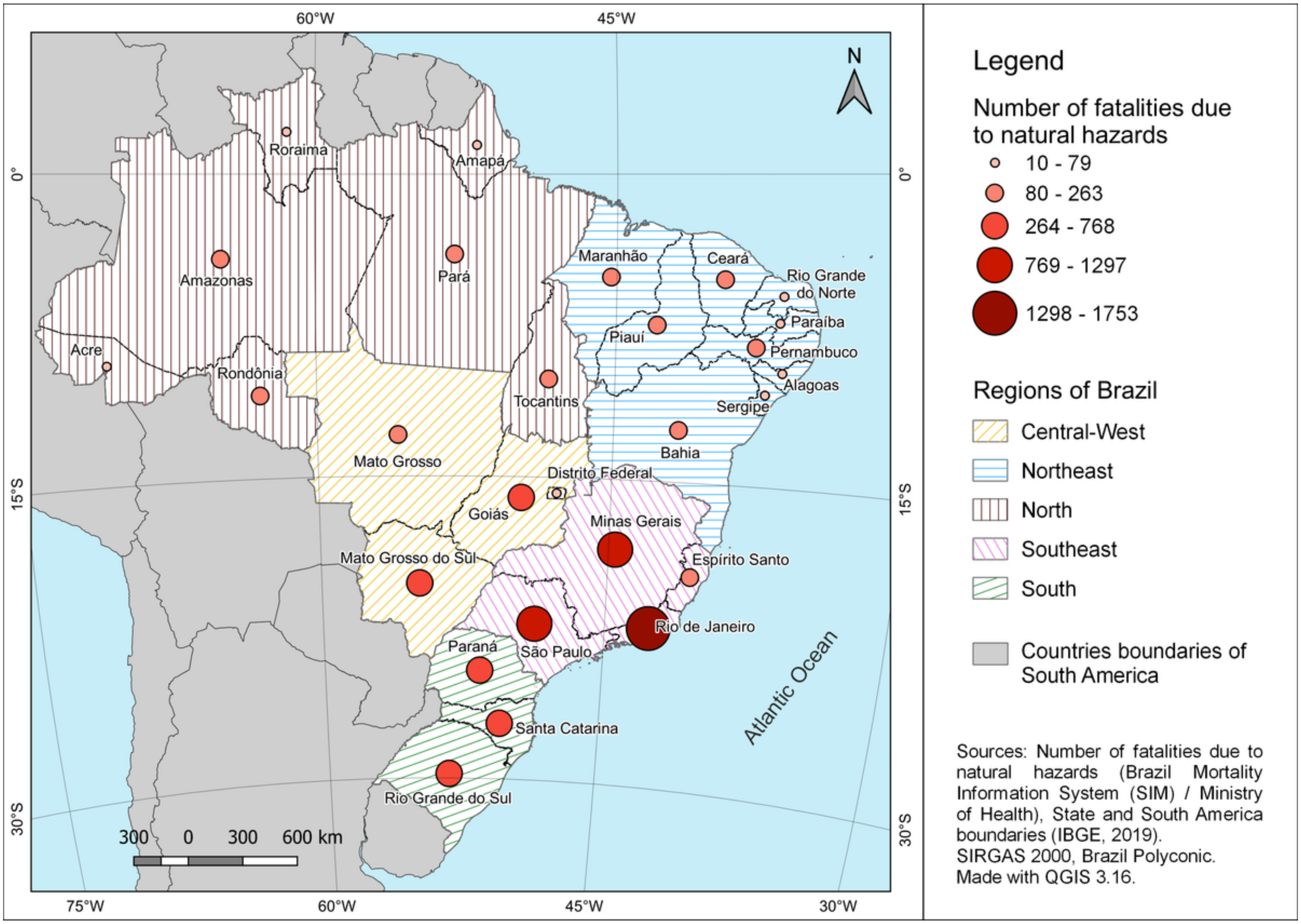

Figure 8

Territorial distribution of all categories of natural hazards fatalities for the period from 1979 to 2019 in Brazil. The size of each point indicates the number of deaths along the forty years.

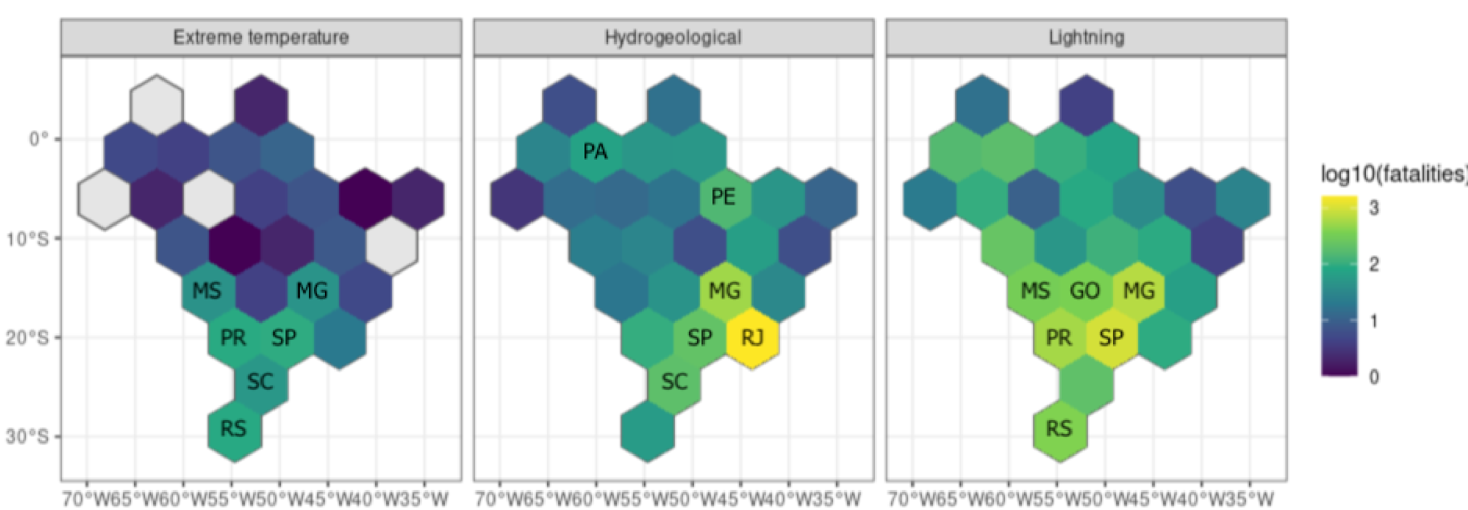

Figure 9

Spatial distribution of the three different groups of natural hazards fatalities in Brazil normalized as logarithm. Each image contains the acronyms of the six Brazilian states with higher number of fatalities per natural hazards from 1979 to 2019.

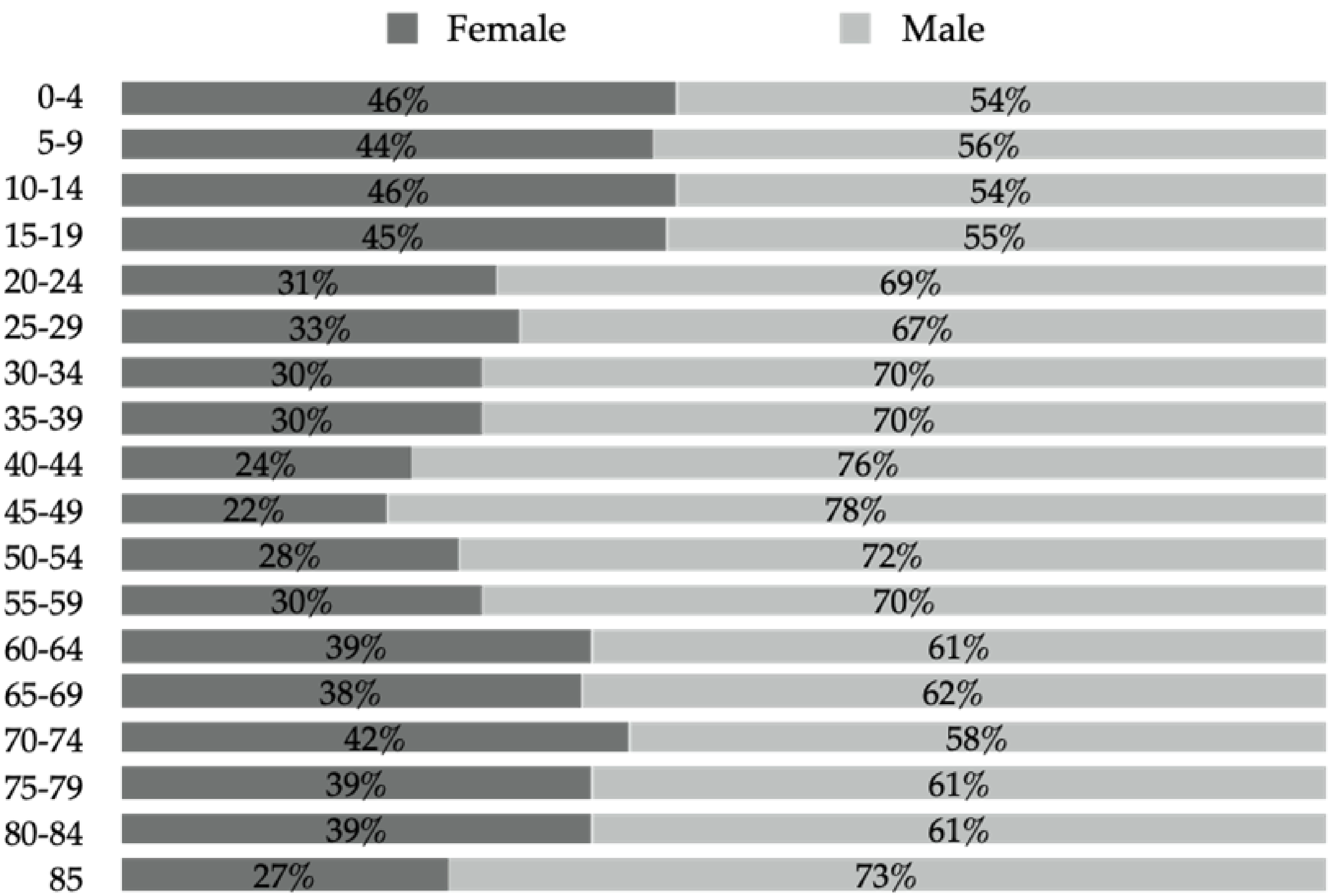

Figure 10

Number of female (on the left) and male (on the right) fatal victims by age groups of hydrogeological and extreme temperature categories of natural hazards from 1979 to 2019 in Brazil.

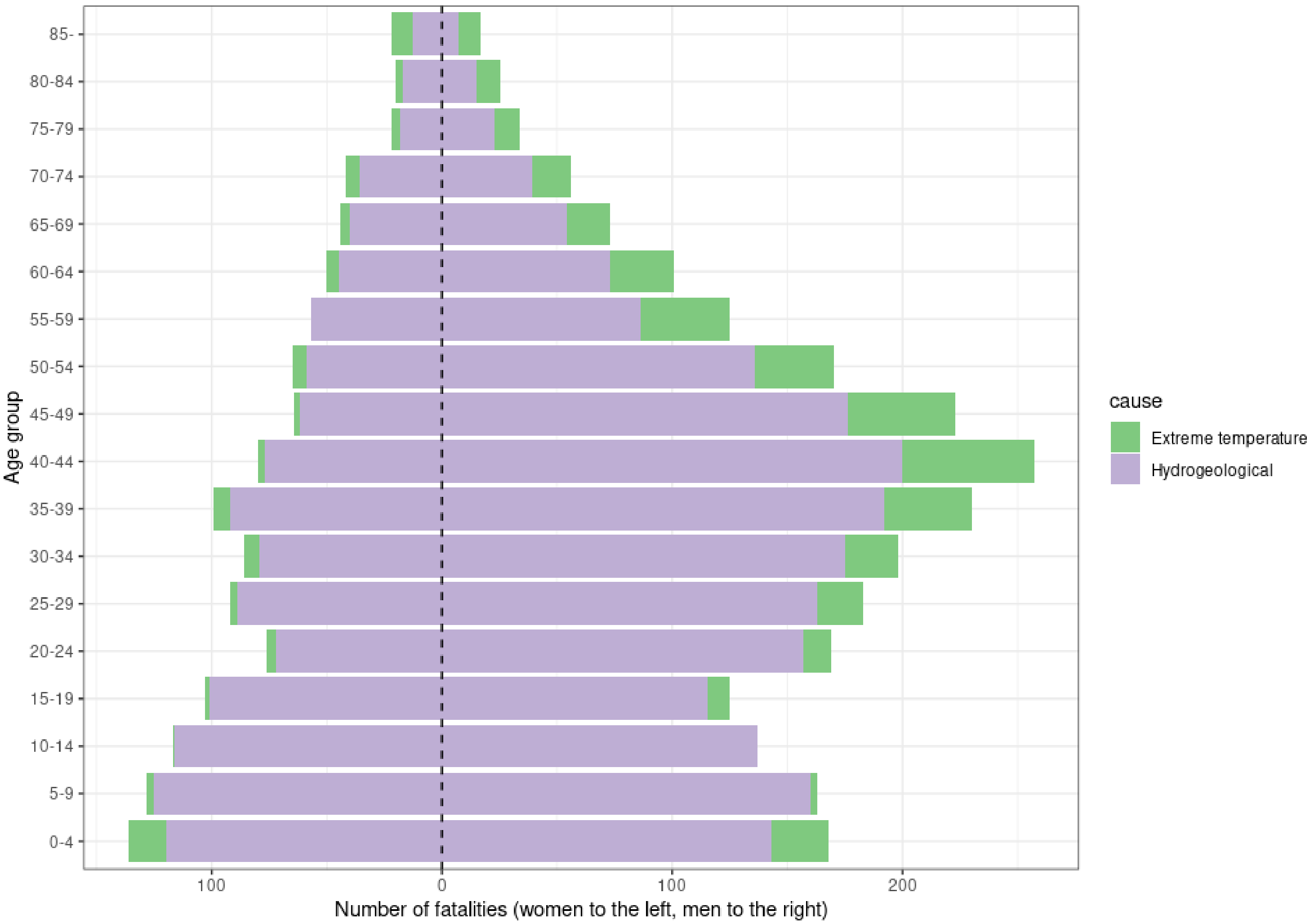

Figure 11

Age pyramid of number of fatalities by sex (female on the left and male on the right) and age group disaggregated by category of natural hazard; extreme temperature on green and hydrogeological on purple.

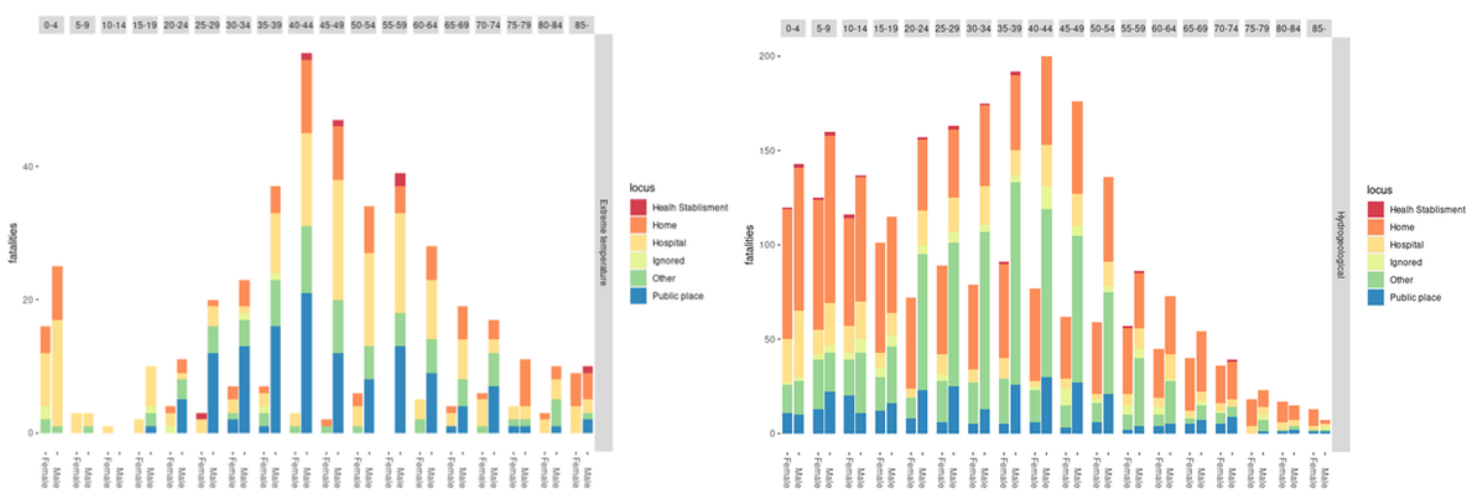

Figure 12

Number of fatalities disaggregated by sex, age group, locus of fatalities and category of natural hazard; extreme temperature on the left and hydrogeological on the right in Brazil, from 1979 to 2019.

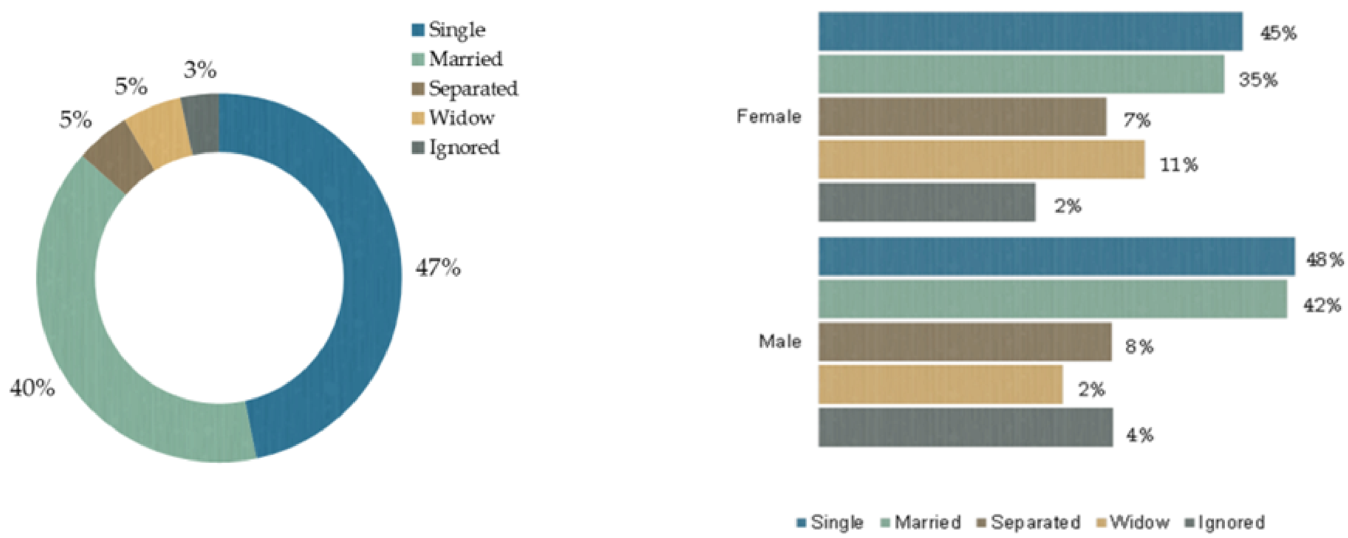

Figure 13

On the left (Fig 13a) is referred to the percentage of the marital status of all fatally affected victims from 1979 to 2019. On the right, (Fig 13b) the same percentage disaggregated by sex.

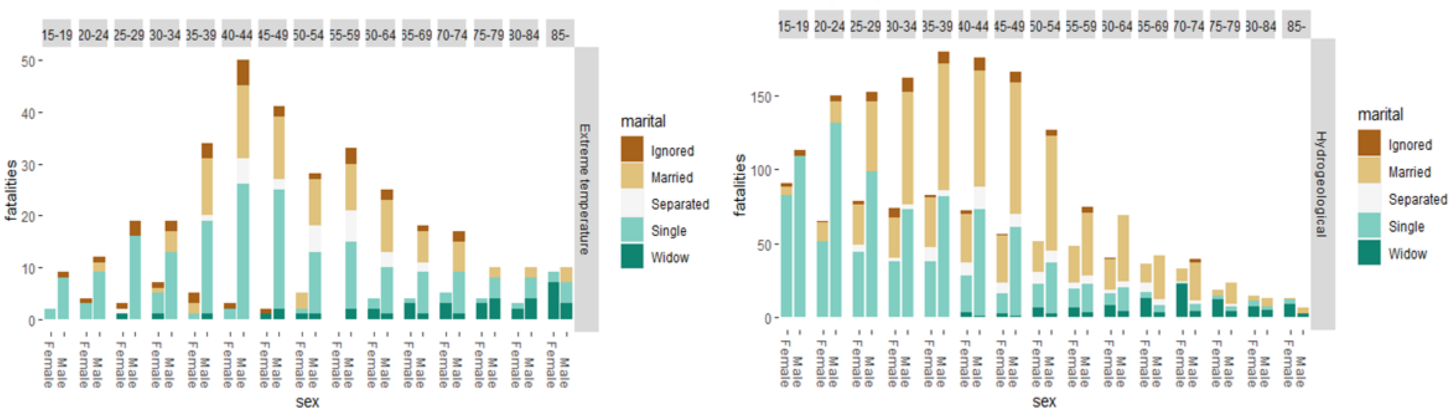

Figure 14

Number of fatalities disaggregated by sex, age group, marital status and category of natural hazard; extreme temperature on the left and hydrogeological on the right in Brazil, from 1979 to 2019.

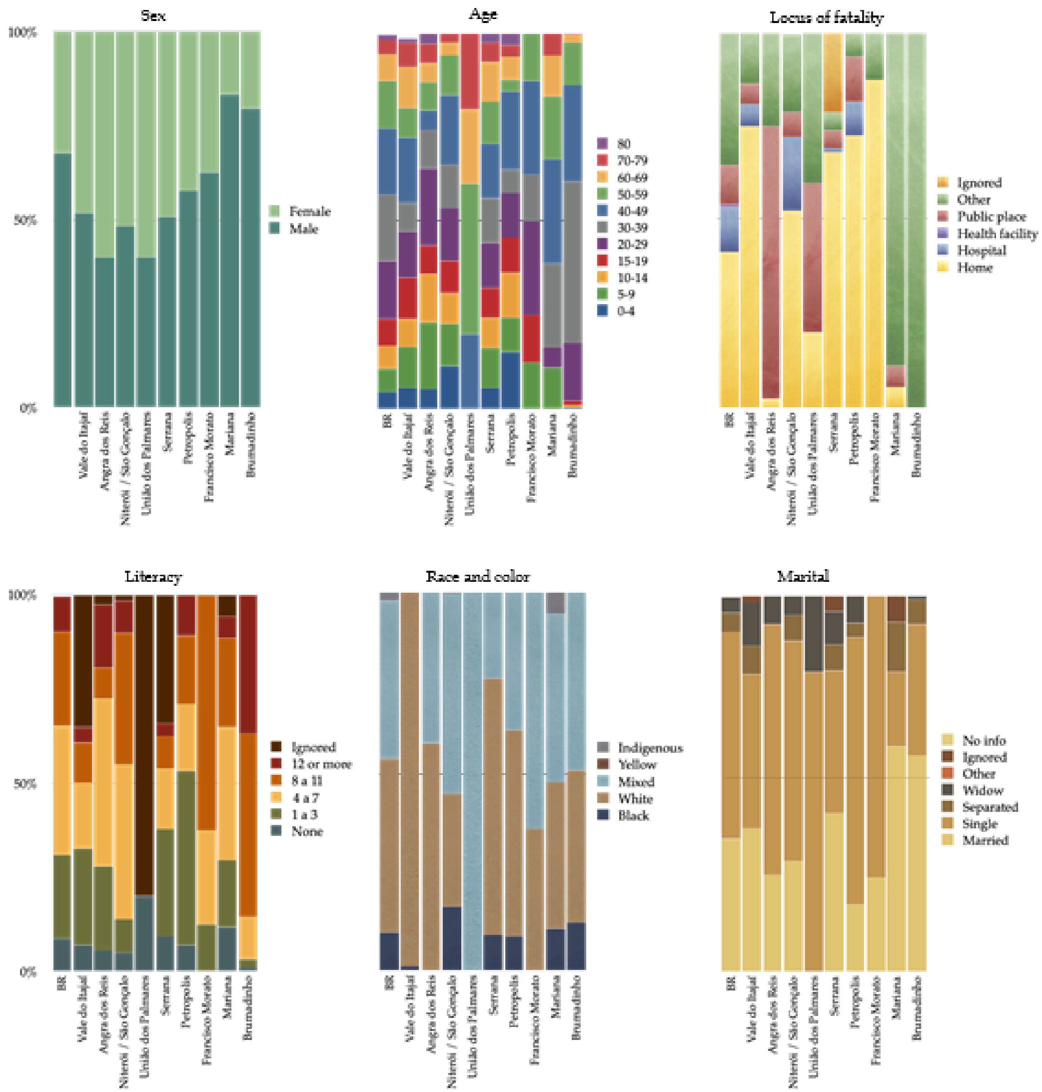

Figure 15

Percentage distribution of fatalities by sex, age group, locus of fatalities, literacy, race and color and marital status of the victims who died in Brazilian disasters.