Demographic yearbooks as a source of weather-related fatalities: The Czech Republic, 1919–2022

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Abstract. Demographic yearbooks of the Czech Republic, prepared by the Czech Statistical Office for the period 1919–2022, contain official figures for the number, gender, and age of fatalities attributed to excessive natural cold, excessive natural heat, lightning, natural hazards~~disasters~~, air pressure changes, and falls on ice or snow, covering a 104-year period or its parts. These yearbooks, influenced by evolving international classifications of diseases, tend to underestimate the fatality numbers for excessive natural heat, natural hazards~~disasters~~, and especially air pressure changes. Out of a total of 9,259 weather-related fatalities (with a mean annual rate of 89.0 fatalities), 74.9 % were caused by excessive natural cold and 19.3 % by lightning. ~~Except for a zero linear trend in natural disasters,~~ No trend was identified in natural hazards, whilst statistically significant decreasing trends were found for lightning fatalities, and increasing trends for excessive natural cold, excessive natural heat, and falls on ice or snow. Males and seniors aged ≥65 years were the most common gender and age categories affected. The number of fatalities attributed to excessive natural cold has partly increased as a result of the gradually aging population and the rise in the number of homeless people since the 1990s. A statistically significant relationship between cold-related fatalities and mean January–February and winter (December–February) temperatures was established, evidenced by high negative correlation coefficients. Lightning deaths have notably decreased since the 1970s, primarily due to a significant reduction in the number of people employed in agriculture, an increase in urban population, better weather forecasting, lifestyle changes, and improved medical care. Although there is a significant positive correlation between these fatalities and the number of days with thunderstorms, the relationship is relatively weak. The results obtained for the Czech Republic align well with similar studies in Europe and elsewhere. While the demographic yearbooks cover only a part of weather-related fatalities, their circumstances, and characteristics, combining them with other similar databases is crucial to gain necessary knowledge usable in risk management for the preservation of human lives.

1 Introduction

Weather and climatic extremes have always been accompanied by a loss of human lives. Globally, the highest numbers of weather-, climate-, and water-related fatalities, particularly from 1970 to 2019, were attributed to tropical cyclones (38 %) and, on a continental scale, predominantly in Asia with 47 % of all deaths (WMO, 2021). Recent global warming has significantly altered the nature of these weather extremes and expanded their impact to other continents. According to Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters' (CRED, 2024) ~~Emergency Events Database (EM-DAT)~~, Europe experienced a total of 1,672 disastrous events between 1970 and 2019, with economic damages amounting to US$ 476.5 billion. The number of fatalities increased dramatically, from 9,953 in the three decades from 1970 to 1999 to 82,919 and 66,566 in the two subsequent decades, respectively; in total, 148,109 fatalities (i.e., 92.9 % of all 159,438 fatalities from 1970 to 2019) were attributed to heat waves (WMO, 2021). This is related to the increasing frequency and severity of heat waves (e.g., Vicedo-Cabrera et al., 2021; Lhotka and Kyselý, 2022). Forzieri et al. (2017) even warned that the annual exposure to weather-related disasters in Europe, which affected 25 million people during 1981–2010, could rise to 351 million by 2100, mainly due to an increase in heat wave frequency. The rising number of disastrous events, economic damage, and fatalities led to the adoption of The Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on 18 March 2015. With the goal of "preventing new and reducing existing disaster risks," the Framework proposed corresponding targets and priorities (UNODRR, 2020; Wright et al., 2020).

Weather-related fatality data are collected by various entities at the national level, such as ministries, statistical offices, and health offices, and by different agencies at international, continental, or worldwide scales, including the European Environment Agency (2023) and re-insurance agencies like MunichRe. Specific databases dedicated to this data collection have been established (e.g., Guha-Sapir et al., 2016; Paprotny et al., 2018a; Petrucci et al., 2019b; Papagiannaki et al., 2022). These databases, which include various types of data and characteristics of fatalities, enable a range of analyses (e.g., Paprotny et al., 2018b; Petrucci et al., 2019a; Vinet et al., 2019).

The data entered into weather-related databases often originate from diverse documentary sources, both official and otherwise. Newspapers are a significant source, widely used in creating national databases that subsequently support detailed analyses of different aspects of deadly events at the national level, as seen in countries like Switzerland (Hilker et al., 2009), Portugal (Zêzere et al., 2014), southern France (Vinet et al., 2016), Calabria in southern Italy (Aceto et al., 2017; Petrucci et al., 2018), and Mallorca (Grimalt-Gelabert et al., 2020). However, as is typical with documentary data (e.g., Brázdil et al., 2019), these sources may exhibit spatial and temporal inconsistencies and potentially undervalue the actual number of fatalities. In this context, demographic yearbooks, which contain official mortality data, represent a particularly valuable resource.

In the Czech Republic, analyses of weather-related fatalities have utilized official medical statistics to study fatalities related to heat waves (e.g., Kyselý and Kříž, 2008; Kyselý and Plavcová, 2012; Urban et al., 2017) and cold waves (e.g., Kyselý et al., 2009; Plavcová and Urban, 2020). While heat wave fatalities are often poorly covered in newspapers, detailed information on many other weather extremes is available, as documented in several related studies (e.g., Brázdil et al., 2022a, 2023a). Brázdil et al. (2021) compared their documentary-based fatality database with the data from the Czech Statistical Office for the period 2000–2019, discussing the differences that emerged.

Following the establishment of the former Czechoslovakia after the end of the First World War in 1918, demographic yearbooks began to be published annually from 1919 as an official source summarizing various aspects of population development. These yearbooks provide a means to analyze corresponding weather-related fatalities within recent Czech Republic territory over the period 1919–2022. This analysis is facilitated by the fact that each yearbook includes not only the number of deceased, but also details regarding the causes of death. The aim of our paper is to present results and discuss the potential of such data in the study of weather-related fatalities over a 104-year period, focusing on individual weather extremes, long-term trends, and the gender and age of the fatalities.

2 Data

2.1 The Czech Republic

The Czech Republic (CR), a Central European country with an area of 78,887 km^2 and a population of 10,827,529 as of 31 December 2022, emerged from the division of former Czechoslovakia into the Czech and Slovak Republics on 1 January 1993. Czechoslovakia was initially formed on 28 October 1918 before~~following~~ the end of the First World War (11 November 1918), comprising the historical Czech lands of Bohemia, Moravia, and southern Silesia, along with Slovakia. After the Munich Agreement on 30 September 1938, the Czech Lands lost the Sudetenland, and following Nazi occupation on 15 March 1939, they became the Protectorate of Bohemia and Moravia (with Slovakia separating), existing until the end of the Second World War in 1945, when Czechoslovakia was re-established. The communist coup in 1948 and the “Velvet Revolution” in 1989, which marked the beginning of democratic development, were other significant events in the history of former Czechoslovakia. In 2004, the CR joined the European Union.

2.2 Fatality data

The Czech Statistical Office (CSO) has provided annual demographic data, specifically for the current CR territory, extracted from Czechoslovak yearbooks for the 1919–1992 period and published in subsequent yearbooks for the CR from 1993 to 2022 (Český statistický úřad, 2023a). Among other things, these mortality data enable the collection of information about the number, gender, and age of fatalities attributed to various causes of death, including weather and natural phenomena listed under external causes of death (Table 1). The causes of death are based on the International List of Causes of Death and later on the International Classification of Diseases, revised under the auspices of the World Health Organization (2023). Due to changes in the accepted list of death causes over various periods (which occurred in yearbooks from 1931, 1949, 1968, and 1994), specific weather-related fatalities could only be collected for different intervals during the entire 1919–2022 period (Table 1). Exceptions include fatalities attributed to exposure to excessive natural heat, excessive natural cold, and lightning, which have been reported throughout the entire period analyzed. Similar issues arose with changes in the delimitation of age categories for which corresponding numbers of male and female fatalities were presented in the yearbooks (Table 2).

Table 1. Categories of external death causes attributed to weather and natural extremes and the periods in which they were available in annual demographic yearbooks for the Czech Republic during the 1919–2022 period.

Death causes	Number, code	Period
excessive natural cold	193, 190, E932, E901, X31	1919–2022
excessive natural heat	194, 191, E931, E900, X30	1919–2022
lightning	195, 192, E935, E907, X33	1919–2022
natural hazards~~disaster~~	187, E934	1931–1978
high and low air pressure and its changes	E930, E902	1949–1993
natural hazards~~disasters~~ and flooding caused by them	E908	1979–1993
catastrophic movement of surface and (volcanic) eruptions	E909	1979–1993
solar radiation	X32	1994–2022
avalanche, landslide or other earth movement	X36	1994–2022
natural catastrophic storm	X37	1994–2022
flood (inundation)	X38	1994–2022
other and/or non-specified natural forces	X39	1994–2022
fall on ice or snow	W00	1994–2022

Table 2. Age categories of fatalities attributed to weather and natural extremes and the periods in which they were available in demographic yearbooks during the 1919–2022 period (the age category 1–4 was divided into 1, 2, 3, 4 years from 1949 to 2007; x – unknown age).

Age category (years)	Period
0, 1–4, 5–9, 10–14, 15–19, 20–29, 30–39, 40–59, 60–79, 80+, x	1919–1924
0, 1–4, 5–14, 15–24, 25–39, 40–49, 50–64, 65+, x	1925–1930
0, 1–4, 5–14, 15–24, 25–34, 35–44, 45–54, 55–64, 65+, x	1931–1940
0, 1–4, 5–14, 15–24, 25–34, 35–44, 45–54, 55–64, 65–74, 75+, x	1941–1945
0, 1–4, 5–14, 15–24, 25–34, 35–44, 45–54, 55–64, 65–74, 75–84, 85+, x	1946–1959
0, 1–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85+	1960–2007
0, 1–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–89, 90–94, 95+	2008–2022

The data from demographic yearbooks can be supplemented for the period 1986–2022 with more detailed information from the internal CSO database. This database provides specifics about each fatality, including the date, age, gender, level of education, place of permanent residence, and cause of death, with additional information on the place of death included from 2010 onwards.

2.3 Meteorological data

For the comparison of fatality data with weather/meteorological patterns, two meteorological series covering the entire territory of the CR were used:

(i) Temperature series

The mean monthly areal temperature series for the CR was calculated from long-term observations at meteorological stations of the Czech Hydrometeorological Institute (CHMI) for the period 1800–2010 (Brázdil et al., 2012). This series was later extended to include data up to 2022.

(ii) Thunderstorm series

The mean annual number of days with thunderstorms was calculated as the median from series at eight CHMI meteorological stations (Brno, České Budějovice, Klatovy, Liberec, Milešovka, Olomouc, Prague-Karlov, and Teplice – see Fig. 1A) that have recorded thunderstorm observations throughout the entire 1919–2022 period.

3 Methods

Based on the fatality data attributed to various causes of death listed in Table 1, the following series of fatalities according to different weather categories were created from the demographic yearbooks:

(i) Excessive natural cold, 1919–2022 (numbers/codes of death causes: 193, 190, E932, E901, and X31);
(ii) Excessive natural heat, 1919–2022 (numbers/codes of death causes: 194, 191, E931, E900, X30, and X32);
(iii) Lightning, 1919–2022 (numbers/codes of death causes: 195, 192, E935, E907, and X33);
(iv) Natural hazards~~disaster~~, 1931–2022 (numbers/codes of death causes: 197, E908, E909, E934, X36, X37, X38, and X39);
(v) High and low air pressure and its changes, 1949–1993 (codes of death causes: E930 and E902);
(vi) Fall on ice or snow, 1994–2022 (code of death cause: W00).

The above six series in points (i)–(vi) consist of annual numbers of related fatalities, their gender, and age categories (see Table 2). Temporal fluctuations in these series (except point v) were visualized in figures, and their linear trends in the corresponding periods were calculated using the non-parametric Theil-Sen method, which is more robust against outliers in time series (Sen, 1968; Theil, 1992). The non-parametric Mann-Kendall test was further employed to evaluate the statistical significance of linear trends (Mann, 1945; Kendall, 1975). For annual numbers of all weather-related fatalities, their proportions of the total numbers of all deaths in the given year were calculated. Pearson correlation coefficients were used to determine relationships between fatalities related to excessive natural cold and mean temperatures on one hand, and between lightning fatalities and the number of days with a thunderstorm on the other. The significance of the correlation coefficients was assessed using a t-test. To mitigate the effects of non-meteorological factors in fatality series, corresponding pairs of series were first detrended using a high-pass filter and then correlated.

Based on individual fatality data from the CSO database, a similar analysis as reported above was conducted for the 1986(1994)–2022 period. Additionally, this allowed for an analysis of the annual variation of fatalities according to individual months and an investigation of the relationship between fatalities attributed to excessive natural cold and mean winter temperatures in the CR using the Pearson correlation coefficient.

4 Results

4.1 Long-term fatality trends in 1919–2022

According to data from demographic yearbooks (Table 1), a total of 9,259 weather-related fatalities were recorded in the CR during the 1919–2022 period, averaging 89.0 fatalities per year (Table 3). The majority (74.9 %) of these were due to excessive natural cold (66.7 fatalities/year), followed by lightning (19.3 %, 17.2 fatalities/year). For the same period, fatalities attributed to excessive natural heat accounted for only 3.5 % (3.1 fatalities/year), while the other three groups of fatalities, reported for much shorter periods, comprised 1.5 % for natural hazards~~disasters~~, 0.7 % for falls on ice or snow, and only 0.1 % for air pressure changes. Fatalities predominantly involved males (72.3 %) compared to females (27.7 %). Among the six weather categories, the highest proportion of male and the lowest of female fatalities were observed in the category of excessive natural cold (75.2 % male to 24.8 % female), while the opposite extreme proportions were recorded for excessive natural heat (62.4 % male to 37.6 % female), slightly higher than for lightning (63.2 % male to 36.8 % female).

Table 3. Numbers of all weather-related fatalities divided between males and females in the Czech Republic during the 1919–2022 period, based on data from demographic yearbooks: FN – absolute number of fatalities, MNF – mean number of fatalities per year, FN1 – relative proportion (%) of all weather-related fatalities, FN2 – relative proportion (%) within the related weather category.

Weather category	**Period**	**FN**	**MNF**	**FN1**	**Males**		**Females**	
					FN	FN2	FN	FN2
excessive natural cold	1919–2022	6933	66.7	74.9	5212	75.2	1721	24.8
excessive natural heat	1919–2022	322	3.1	3.5	201	62.4	121	37.6
lightning	1919–2022	1786	17.2	19.3	1128	63.2	658	36.8
natural hazards~~disaster~~	1931–2022	142	1.5	1.5	99	69.7	43	30.3
air pressure	1949–1993	10	0.2	0.1	7	70.0	3	30.0
fall on ice/snow	1994–2022	66	2.3	0.7	48	72.7	18	27.3
Total	1919–2022	9259	89.0	100.0	6695	72.3	2564	27.7

Long-term fluctuations in weather-related fatalities in the CR during the 1919–2022 period exhibit different patterns (Fig. 1), which can be characterized as follows:

(i) Excessive natural cold

The number of fatalities related to excessive natural cold displays three distinct periods: initially high values from 1919, with a decreasing trend until the early 1940s, followed by lower numbers until the late 1970s, after which a significant increase began, continuing until 2022. The highest annual tolls were 186 deaths in 2010, 174 in 2009, 170 in 2021, and 162 in 1929. While the winter of 1928/29, with a mean temperature of –7.6 °C, was the coldest of the past century in the CR (Křivancová, 1999; Krška, 2009; Brázdil et al., 2019), the other three winters were milder, ranging between –2.3 °C (2009/10) and 0.2 °C (2020/21). The series as a whole exhibits a statistically significant increasing linear trend, with a slope of 9.4 fatalities/10 years ($p < 0.01$).

(ii) Excessive natural heat

Data on fatalities associated with excessive natural heat are less abundant. While 34 deaths were recorded in 1921 (during a warmer and dry summer in Europe – see van der Schrier, 2021), more than ten fatalities per year were only reported in 1928–1930 (45 in total) and in 1935–1937 (43 in total). In other years, the numbers were mostly below five fatalities, and in 28 years, there were no fatalities of this kind. This pattern is reflected in a statistically significant decreasing trend of –0.4 fatality/10 years ($p < 0.01$).

(iii) Lightning

Fatalities related to lightning also exhibit a statistically significant decreasing linear trend, with a slope of –4.6 fatalities/10 years ($p < 0.01$). A more pronounced decreasing trend is evident from 1919 until the 1970s. From 1976, the annual number of lightning fatalities did not exceed five (except for seven deaths in 1997), with no fatalities recorded in 11 years and only one fatality in ten years.

(iv) Natural hazards~~disaster~~

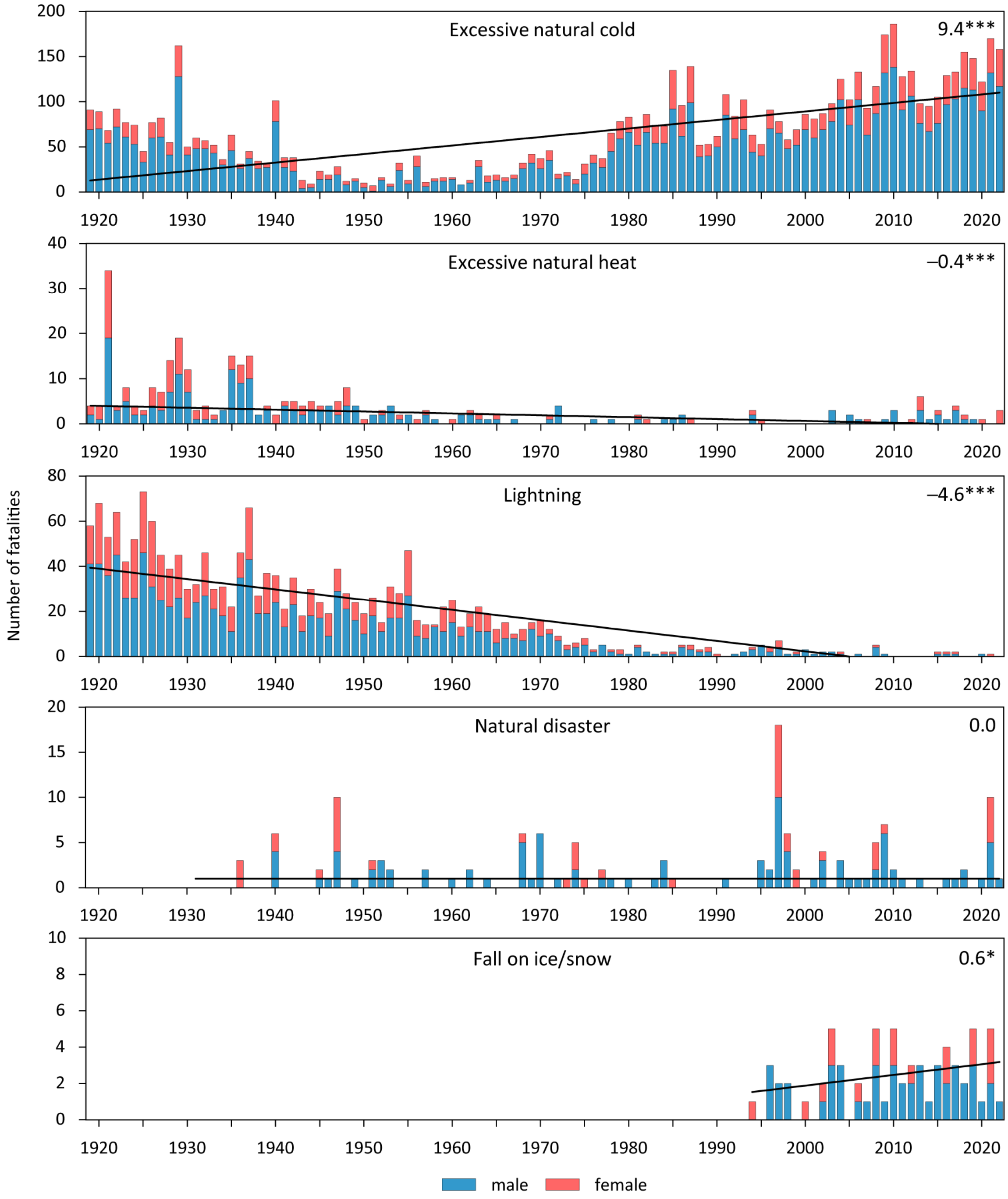
Natural hazards~~disasters~~, not specified in more detail and recorded from 1931, saw the highest number of 18 fatalities in 1997, followed by ten deaths in both 1947 and 2021. There were 43 years since 1931 with no fatalities in this category. Conversely, only six years from 1995 to 2022 had no deaths due to natural hazards~~disasters~~. A zero linear trend was observed in this series.

(v) Fall on ice or snow

Fatalities due to falls on ice or snow, recorded since 1994, did not exceed five deaths in any year (recorded in five years in total), while there were four years with no such fatalities reported. This category exhibits a statistically significant increasing linear trend with a slope of 0.6 fatality/10 years ($p < 0.10$).

(vi) Air pressure

The category of “high and low air pressure and its changes” (not depicted in Fig. 1) accounted for only ten fatalities between 1949 and 1993, recorded in the years 1953, 1954, 1961, 1962, 1965, 1976, and 1990, with each year having one or two fatalities.


Excessive natural cold
9.4***
Excessive natural heat
–0.4***
Lightning
–4.6***
Natural disaster
0.0
Fall on ice/snow
0.6*
Number of fatalities
0
50
100
150
200
10
20
30
40
60
80
5
15
2
4
6
8
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
male
female

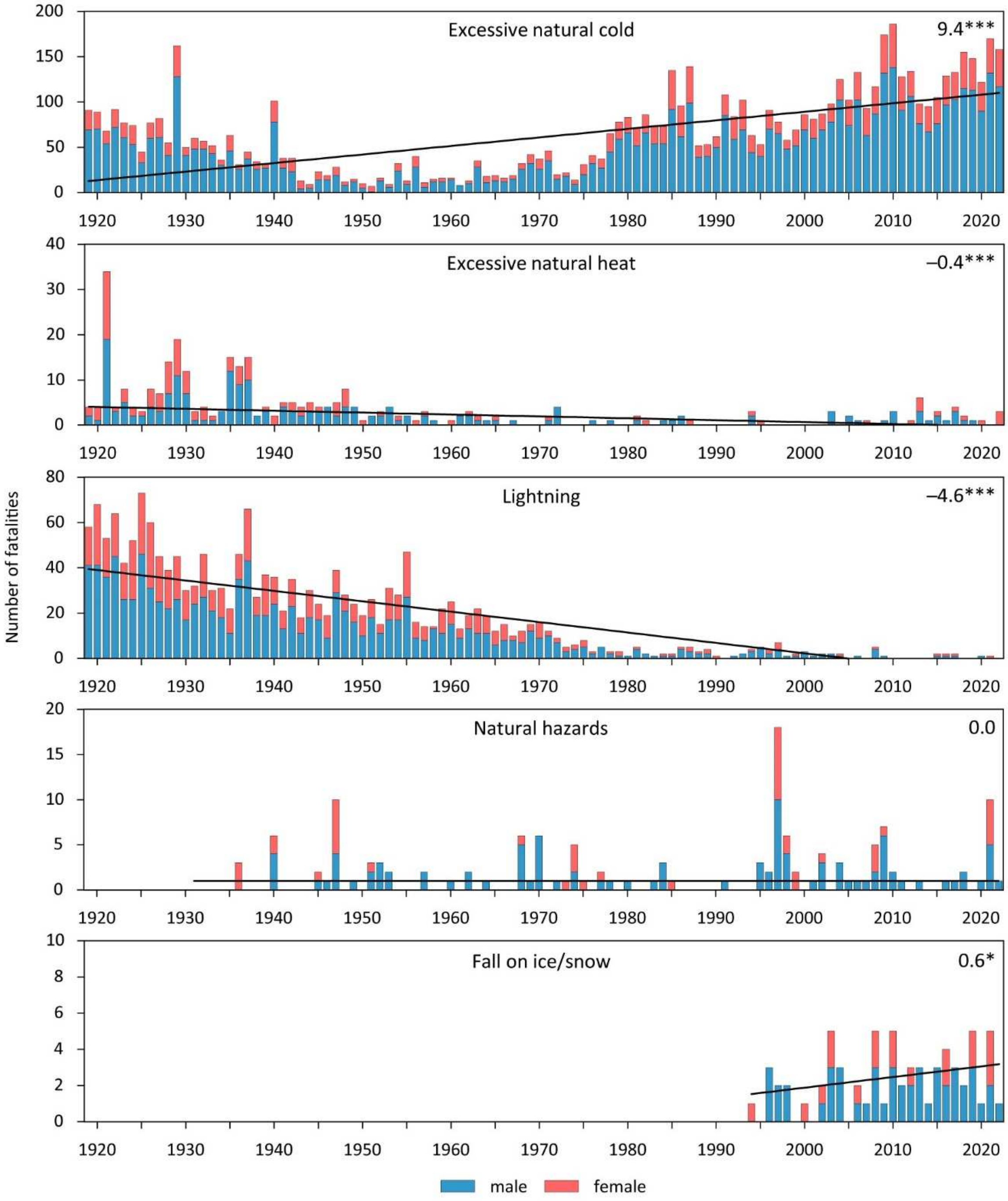


Figure 1. Long-term fluctuations and linear trends in the annual numbers of weather-related fatalities divided by males and females in the Czech Republic during the 1919–2022 period, based on data from demographic yearbooks. Slopes of linear trends

(indicated right above) are expressed as the number of fatalities per 10 years with the following statistical significance: * p < 0.10, *** p < 0.01.

When considering all weather-related fatalities together (Fig. 2a), the two dominant categories of deaths attributed to excessive natural cold and lightning shape the long-term fluctuations. The series is characterized by a clear declining trend from its beginning until the early 1940s, followed by relatively stable fluctuations at much lower levels, and then a significant increase from the mid-1970s until the end of the series. The year 1929 experienced 226 fatalities (particularly due to an extremely cold winter and lightning, as well as a deadly windstorm on 4 July 1929 – Brázdil et al., 2018), followed by the years 2010 (196 fatalities), 2021 (186), and 2009 (184). The lowest numbers were reported in 1961 and 1974 with only 25 weather-related fatalities each, and 28 fatalities in 1973. Annually, the numbers of weather-related fatalities constituted only a very small relative proportion of all deaths in the CR during those years (Fig. 2b) and largely reflected the fluctuations described in Fig. 2a. The mean annual proportion of weather-related fatalities in all deaths for the CR was only 0.74 ‰ (males 1.05 ‰, females 0.42 ‰). Proportions greater than 2 ‰ appeared only in the male category for nine years (with a maximum of 2.70 ‰ in 2010).

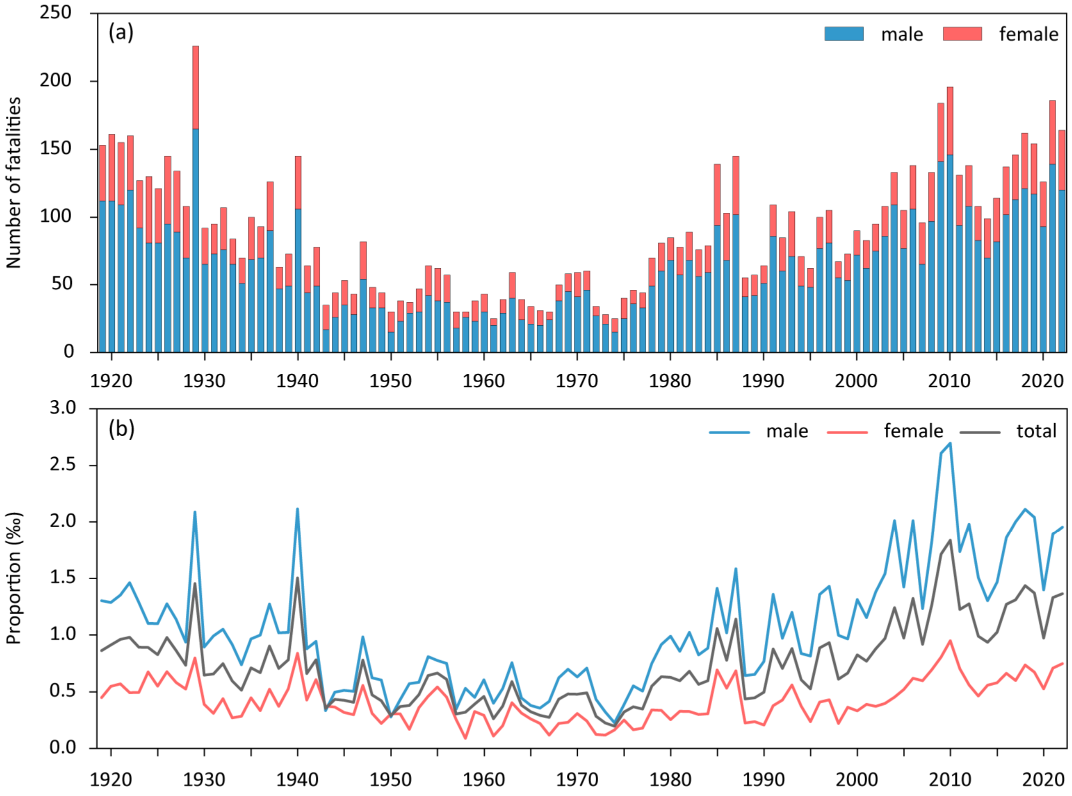
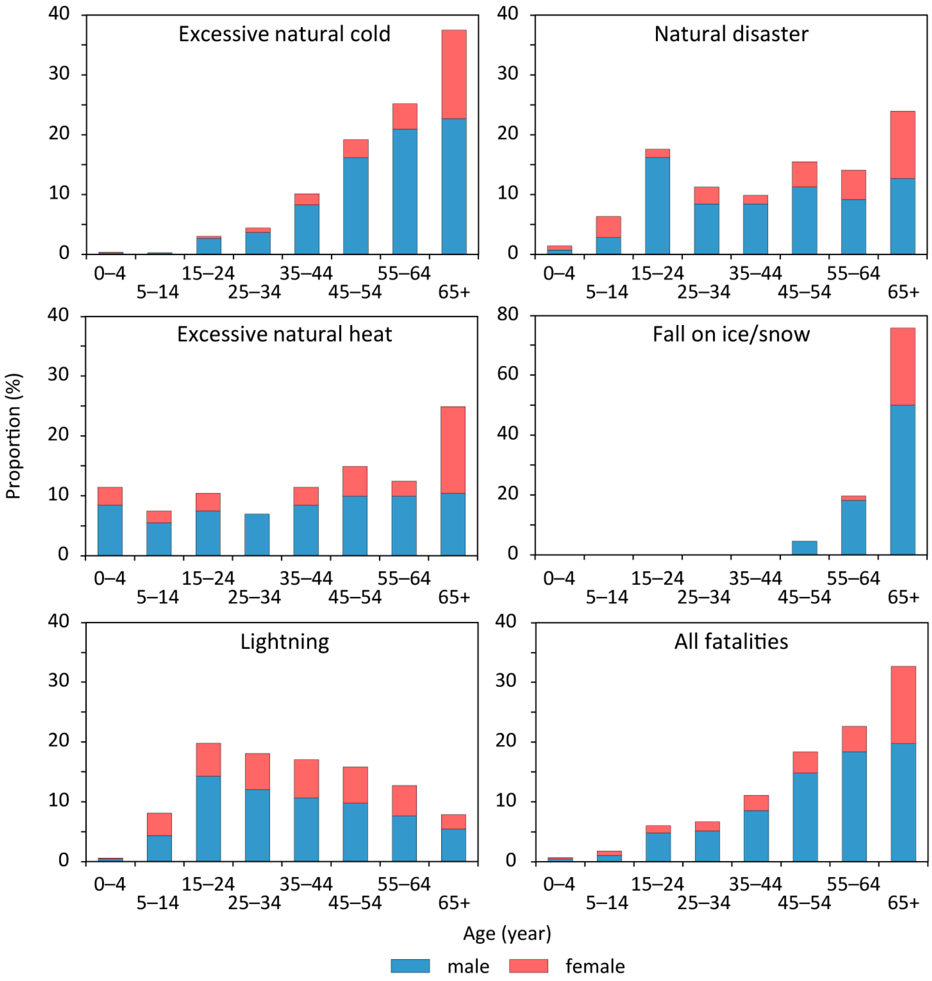


Figure 2. (a) Annual numbers of weather-related fatalities divided by males and females and (b) their relative proportions (‰) in the numbers of total, male, and female deaths in the Czech Republic during the 1919–2022 period, based on data from demographic yearbooks.

Regarding the age structure of weather-related fatalities (Fig. 3a), seniors aged 65 years and older were the most affected group in all categories except lightning. They represented even 75.8 % of fatalities in the category “fall on ice or snow,” with the remaining fatalities in the two age intervals between 45 and 64 years. In the case of excessive natural cold, seniors aged ≥65 years accounted for 37.5 % of related fatalities. The preceding age intervals showed a continuous increase in proportion from ages 15–24 years to senior age. Nearly the same proportions (approximately 25 %) of the highest age group (≥65 years) characterized both excessive natural heat and natural hazards~~disaster~~. Similar proportions were also observed in the age group 45–54 years (approximately 15 %), but in natural hazards~~disasters~~, the age interval 15–24 years reached 17.6 %. The age group 15–24 years was the most frequent for lightning fatalities (19.8 %), followed by a gradual decline in the following age groups to seniors aged ≥65 years (7.8 %), comparable to the children's age interval of 5–14 years (8.1 %). In each of all age categories, the proportions of male fatalities were higher than those of females, except in the age group ≥65 years for excessive natural heat, where the situation was reversed. Considering all categories together, there was a continuous rise in their relative proportions from the youngest (0.7 %) to the oldest (32.6 %) age group. Moreover, the proportion of 6.0 % in the age interval 15–24 years was comparable to 6.7 % in the following interval of 25–34 years. Fig. 3b shows general decreases in relative proportions of age categories 0–14 and 15–64 years in all weather-related fatalities during the 1931–2022 period, while proportions for the category ≥65 years were increasing. Linear trends in proportions of all three age categories were statistically significant ($p < 0.01$): –0.8 %/10 years for 0–14 years, –0.9 %/10 years for 15–64 years, and 1.8 %/10 years for ≥65 years. But both the youngest and oldest age categories showed clear breakpoints around the mid-1970s.


Excessive natural cold
Natural disaster
Excessive natural heat
Fall on ice/snow
Lightning
All fatalities
Proportion (%)
0
10
20
30
40
60
80
0–4
5–14
15–24
25–34
35–44
45–54
55–64
65+
Age (year)
male
female

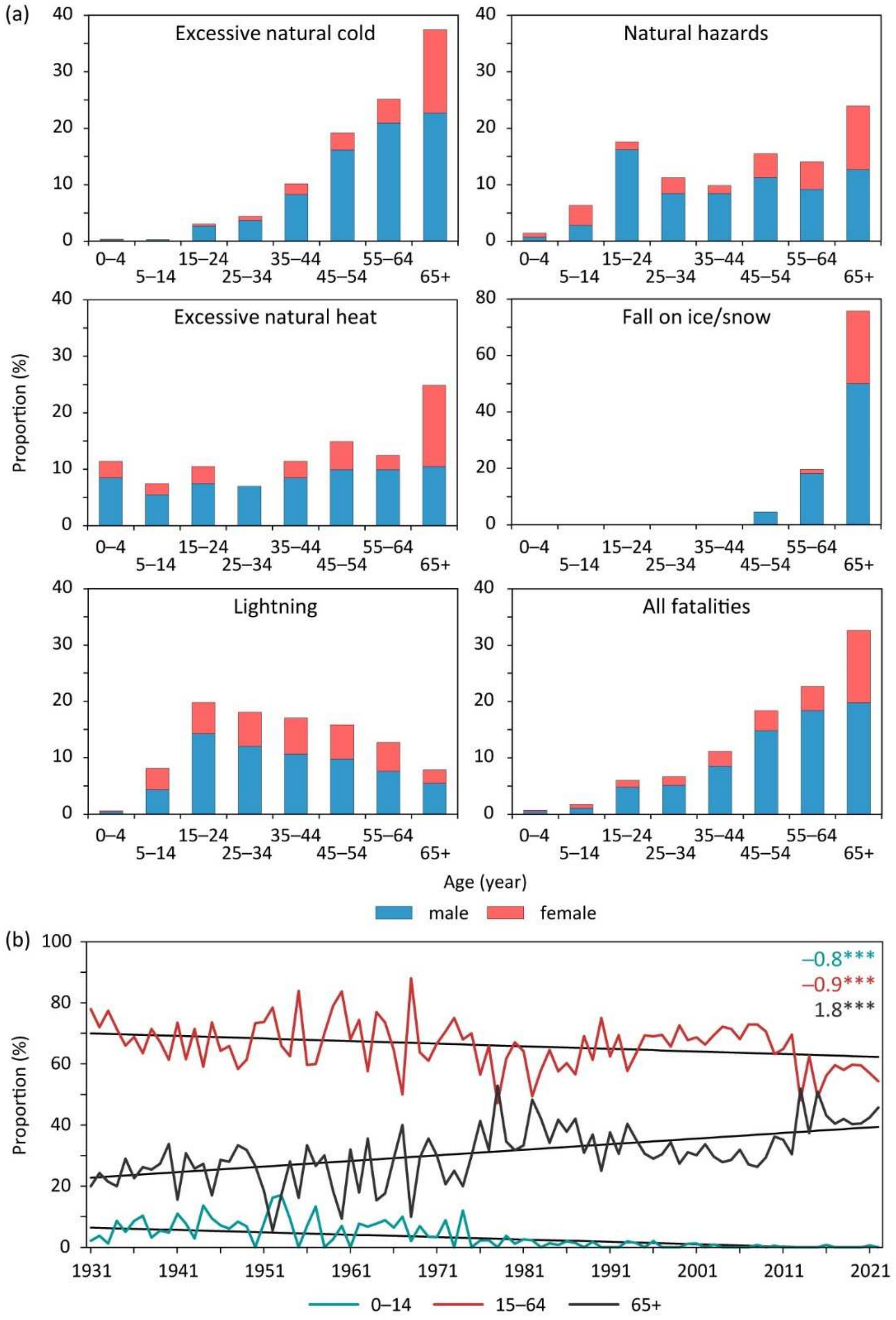


Figure 3. Age and gender structure of ~~Relative proportions (%) of individual and all~~ weather-related fatalities ~~divided according to different age and gender categories~~ in the Czech Republic during the 1931–2022 period, based on data from demographic

yearbooks~~.~~: (a) relative proportions (%) in individual and all weather-related fatalities; (b) fluctuations and linear trends in relative proportions (%) of three age categories in all weather-related fatalities (slopes of linear trends indicated right above are expressed in %/10 years, the statistical significance: *** p < 0.01).

4.2 Structure of fatalities in 1986–2022

The CSO database enabled a more detailed analysis of fatalities attributed to five different weather categories during the 1986(1994)–2022 period, significant in the context of recent global warming (e.g., Zahradníček et al., 2021; Brázdil et al., 2022b). Fig. 4 presents annual fluctuations of related fatalities with linear trends and their statistical significance, variations in fatalities according to individual months, and their gender and age structure for each weather category and all combined, as detailed below.

(i) Excessive natural cold (E901+X31)

A total of 3,965 fatalities were attributed to excessive natural cold from 1986 to 2022, averaging 107.2 fatalities per year (57.2 % of all such fatalities during 1919–2022). The highest number of fatalities was 186 in 2010, followed by 174 in 2009 and 170 in 2021. The lowest numbers were 52 fatalities in 1988, followed by 53 in 1989 and 1995. A statistically significant rising trend was observed at 24.7 fatalities/10 years ($p < 0.01$). During the winter half-year (October–March), 89.7 % of the deaths occurred, with the highest number in January (24.4 %) followed by December (21.0 %). Males accounted for the majority of fatalities (75.1 %). Nearly half of all fatalities were in the age groups 50–59 years (25.8 %) and 60–69 years (22.8 %). In fatalities aged ≥80 years, the proportion of females was higher than that of males.

(ii) Excessive natural heat (E900+X30+X32)

From 1986 to 2022, excessive natural heat was attributed as the cause of death for 50 victims, averaging 1.4 fatalities per year. The maximum of seven fatalities occurred in 2017, followed by six in 2013, but there were 16 years with no deaths from this cause. The series showed a statistically significant increasing trend (0.4 fatalities/10 years, $p < 0.01$). The three summer months dominated the annual variation (72.0 %), with the highest number in June (28.0 %). Males accounted for 64 % of these fatalities, while in the age structure, those aged 80 and older (22.0 %, with a clear female prevalence) and between 50 and 59 years (20.0 %) were predominant.

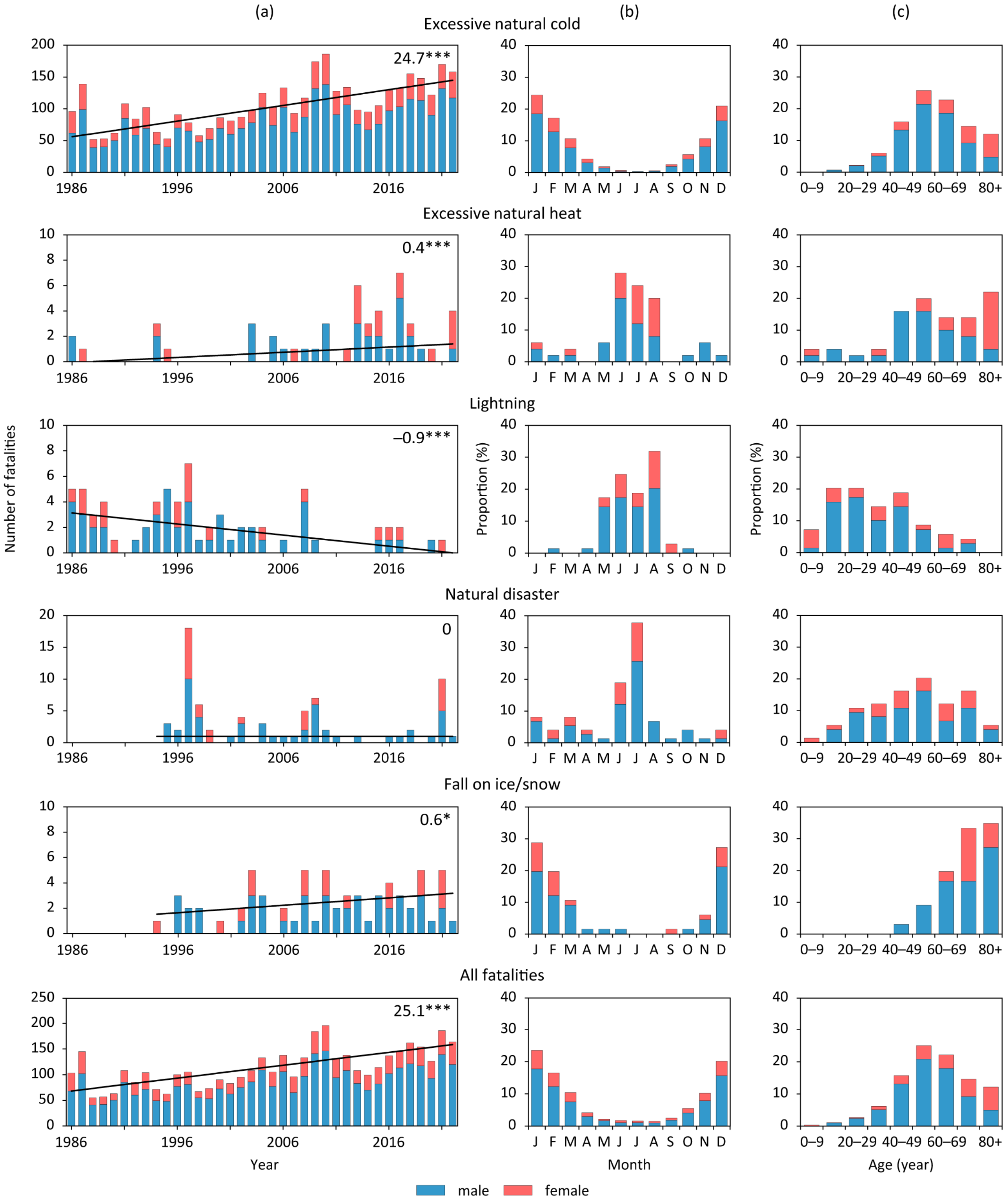
(iii) Lightning (E907+X33)

Between 1986 and 2022, lightning was responsible for 69 deaths, averaging 1.9 fatalities per year. The highest number, seven fatalities, occurred in 1997, followed by five fatalities in four different years. Eleven years had no lightning-related deaths. This series experienced a statistically significant decreasing trend (–0.9 fatalities/10 years, $p < 0.01$). Most fatalities (75.4 %) occurred in the summer months (with an additional 17.4 % in May), peaking in August (31.9 %). The majority of fatalities were males (71.0 %), predominantly in the age ranges of 10–19 and 20–29 years (20.3 % each).

(iv) Natural hazards~~disasters~~ (X36+X37+X38+X39)

A total of 74 fatalities in this category from 1994 to 2022, averaging 2.6 fatalities per year, included victims in four subcategories: 33 fatalities (44.6 %) from floods (inundations); 17 (23.0 %) from catastrophic natural storms; 14 (18.9 %)

from avalanches, landslides, or other earth movements; and 10 (13.5 %) from other and unspecified natural forces. Annual maxima were 18 fatalities in 1997 and 10 in 2021. Of these, 17 deaths in the first case were related particularly to the disastrous July 1997 flood in Moravia and Silesia (Matějíček and Hladný, 1999) and seven deaths in the second case to the deadliest Czech tornado on 24 June 2021 in southern Moravia (Münster, 2022). There were seven years with no fatalities attributed to this category. The series experienced a zero linear trend. Fatalities occurred in all months of the year, with maxima in July (37.8 %) and June (18.9 %). Males suffered 70.3 % of the fatalities. The age group 50–59 years accounted for 20.3 % of all fatalities, followed by the age groups 40–49 and 70–79 years (16.2 % each).


(a)
(b)
(c)
Excessive natural cold
24.7***
Excessive natural heat
0.4***
Lightning
−0.9***
Natural disaster
0
Fall on ice/snow
0.6*
All fatalities
25.1***
Number of fatalities
Proportion (%)
Proportion (%)
1986
1996
2006
2016
J F M A M J J A S O N D
0–9 20–29 40–49 60–69 80+
Year
Month
Age (year)
male
female

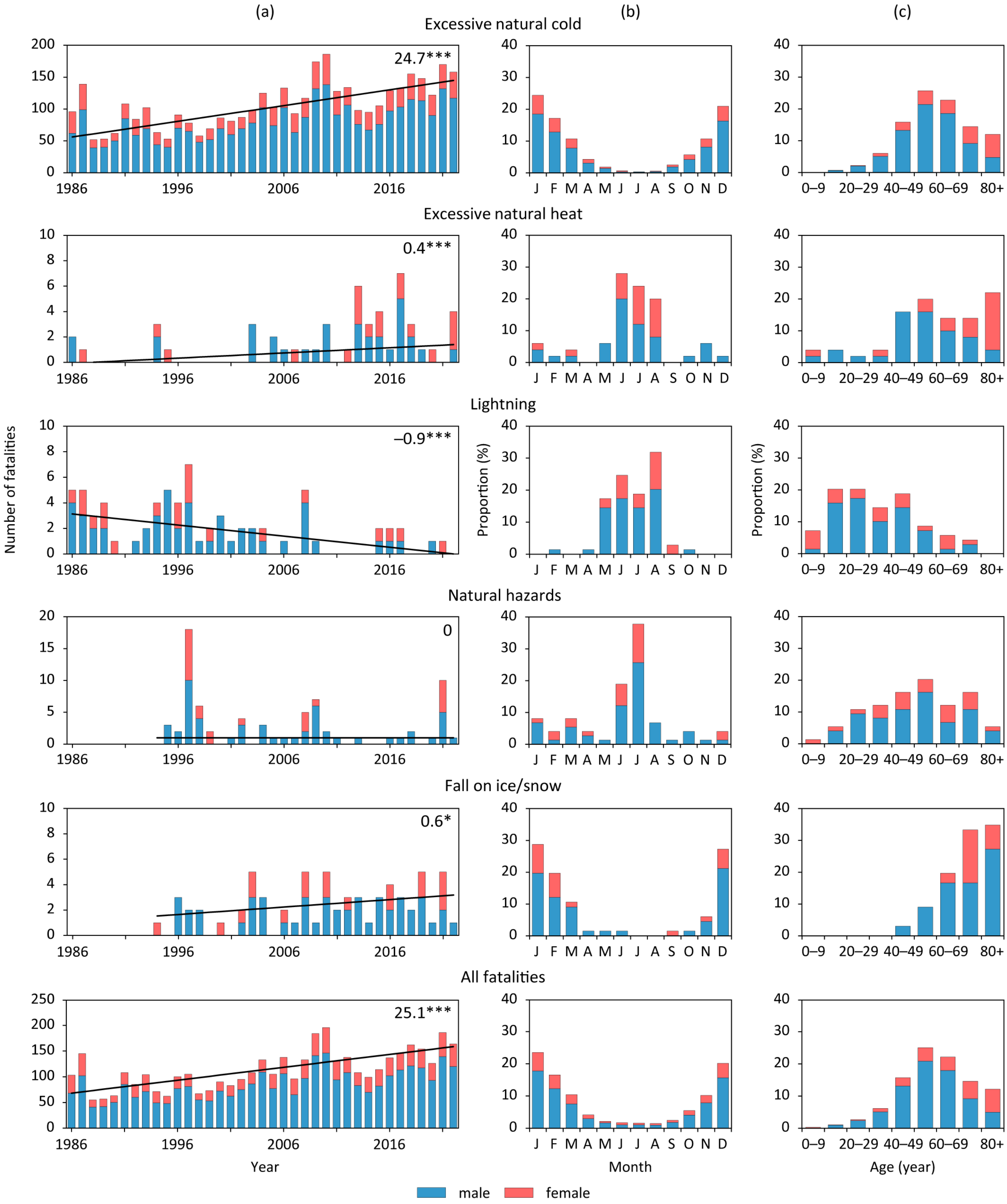

(a)
(b)
(c)
Excessive natural cold
24.7***
Excessive natural heat
0.4***
Lightning
−0.9***
Natural hazards
0
Fall on ice/snow
0.6*
All fatalities
25.1***
Number of fatalities
Proportion (%)
Proportion (%)
1986
1996
2006
2016
J F M A M J J A S O N D
0–9 20–29 40–49 60–69 80+
Year
Month
Age (year)
male
female

Figure 4. Weather-related fatalities divided by males and females in the Czech Republic during the 1986–2022 period for categories of excessive natural cold, excessive natural heat, lightning, natural hazards~~disasters~~, and falls on ice or snow, and for all of them combined: (a) fluctuations with linear trends (right above; statistical significance: * $p < 0.10$, *** $p < 0.01$); (b) annual variation according to monthly values (%); (c) age structure (%) (data: CSO database).

(v) Fall on ice or snow (W00)

From 1994 to 2022, a total of 66 people died due to falls on ice or snow, averaging 2.3 fatalities per year. Maxima of five deaths were recorded in 2003, 2008, 2010, 2019, and 2021, while there were four years with no fatalities. The rising linear trend was statistically significant (0.6 fatalities/10 years, $p < 0.01$). Most fatalities (75.8 %) occurred in the three winter months, with the highest number in January (28.8 %) and in March (10.7 %). In terms of gender and age, 72.7 % of fatalities were males, and 87.9 % were aged 60 years and older (33.3 % in 70–79 years, 34.9 % in 80 years and older).

(vi) All groups (i)–(v) together

When combining all five fatality categories for the 1986–2022 period, out of a total of 4,224 fatalities (114.2 fatalities/year), those related to excessive natural cold accounted for 93.9 %. This means that the characteristics presented for all fatalities largely mirror, with only minor deviations, the features already described for the excessive natural cold category in point (i).

With the inclusion of places of death in the CSO database from 2010 onwards, it is possible to analyze their spatial distribution across the CR for the 2010–2022 period. Of the 1,761 fatalities attributed to excessive natural cold, 61.1 % occurred at the place of permanent residence and 38.9 % at other locations. For the remaining 100 weather-related fatalities (excessive natural heat, lightning, natural hazards~~disaster~~, fall on ice/snow), the distribution was opposite: 40 % at the place of residence and 60 % elsewhere. Given the dominant number of fatalities caused by excessive natural cold, a specific map was created for them (Fig. 5a), while another map was prepared for the other four categories of weather-related fatalities (Fig. 5b). Cold-related fatalities were recorded in 716 municipalities, representing 11.4 % of the total number in the CR. The highest numbers were in larger cities (see Fig. A1 for their locations): Prague (129 fatalities), Ostrava (77), Brno (69), Plzeň (40), Liberec (29), and Hradec Králové (27), collectively accounting for 21.1 % of all cold-related fatalities. A single fatality occurred in 509 municipalities and two in 94. Municipalities with cold-related fatalities formed some larger clusters, such as in a belt parallel to the Czech border in northwestern Bohemia, the area of northern and eastern Bohemia, or the northeastern corner of the CR (Fig. 5a). For the other four categories of fatalities, they were recorded in 55 municipalities (2.1 %) with the highest death numbers in Prague (15 fatalities), Ostrava (seven), Brno (six), Ústí nad Labem (four), Liberec and Plzeň (three each), collectively 38.0 % of all fatalities in these four categories. One fatality occurred in 36 municipalities and two in 13. Besides the reported towns, a higher concentration of such municipalities was again located around the northwestern border of the CR (Fig. 5b).

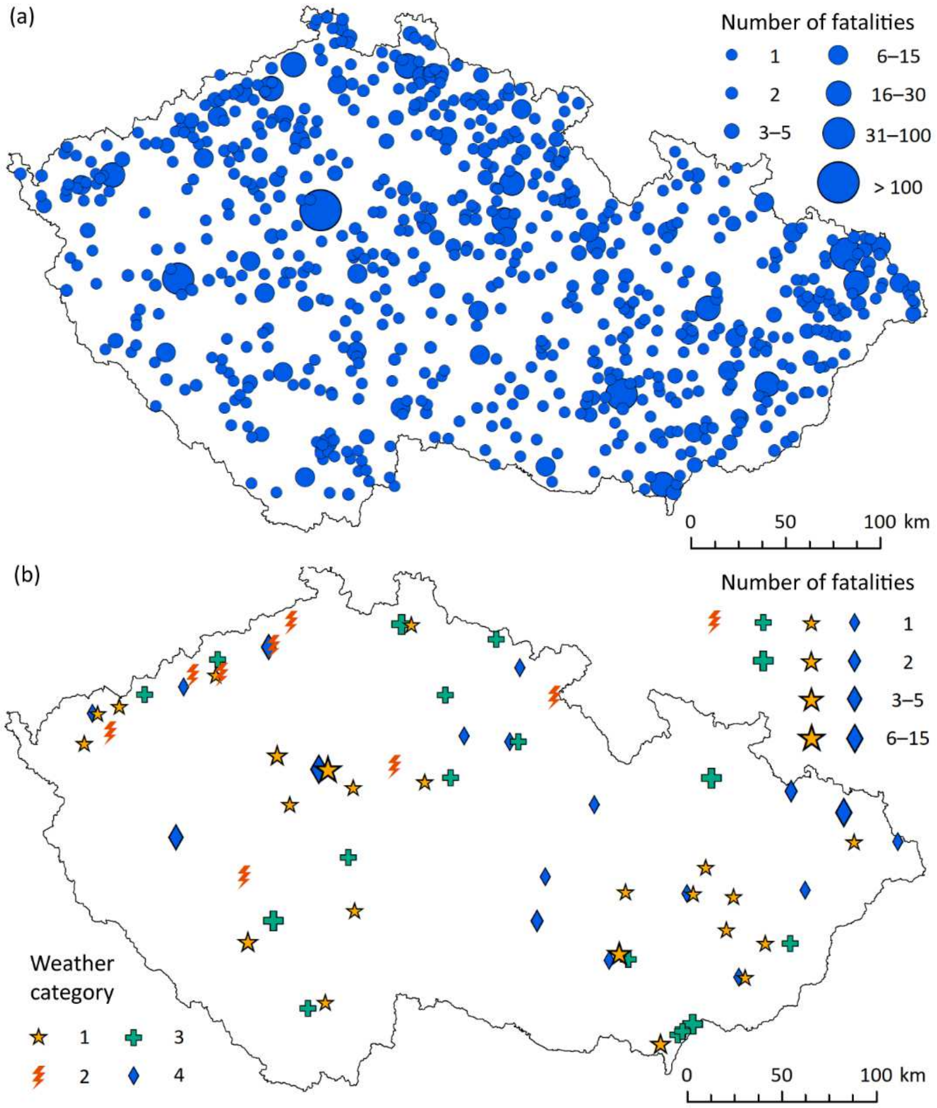


Figure 5. The spatial distribution of weather-related fatalities from the CSO database over the territory of the Czech Republic in 2010–2022: (a) excessive natural cold; (b) weather category: 1 – excessive natural heat, 2 – lightning, 3 – natural hazards~~disaster~~, 4 – fall on ice or snow.

4.3 Relationship of fatalities to meteorological variables

In examining the relationship of weather-related fatalities in the CR to meteorological variables, only two fatality categories – those associated with excessive natural cold and lightning – were deemed suitable for analysis. Other fatalities related to excessive natural heat and natural hazards~~disasters~~ were considered too randomly detected and significantly underestimated for meaningful analysis. Similarly, the shorter series and smaller numbers of fatalities attributed to air pressure changes or falls on ice or snow did not lend themselves to this type of analysis.

4.3.1 Cold-related fatalities and air temperature

For the 1919–2022 period, fatalities attributed to excessive natural cold in the CR were collected annually. To study their relationship with temperature, different combinations of monthly areal temperatures (Sect. 2.3) for the same year were used to identify the series that best correlated with the fatality numbers (not shown). The highest Pearson correlation coefficients were found for the mean temperature series of January–February, which is presented alongside annual fatalities in Fig. 6. Although both series showed statistically significant increasing linear trends (Fig. 6a), the correlations between them varied over time. Dividing the entire fatality series by three historical milestones for the CR (see Sect. 2.1), the significant correlation coefficient from 1919–1945 was –0.47 ($p < 0.05$), indicating that lower temperatures led to higher numbers of deaths. This correlation then decreased to –0.36 ($p < 0.05$) for 1946–1989 and further to a non-significant value of –0.26 for 1990–2022 (Fig. 6a). The temporal fluctuations in the correlation, expressed by 11-year and 21-year running correlations, showed a particular decline in the 1960s–1970s and from the 1990s (Fig. 6b). To describe the relationship of fatalities to January–February temperatures while removing non-meteorological effects, both series in the three above time intervals were first detrended and then correlated. The obtained correlation coefficients were substantially higher (–0.81, –0.74, and –0.58, respectively) and all statistically significant at $p < 0.01$ (Fig. 6c).

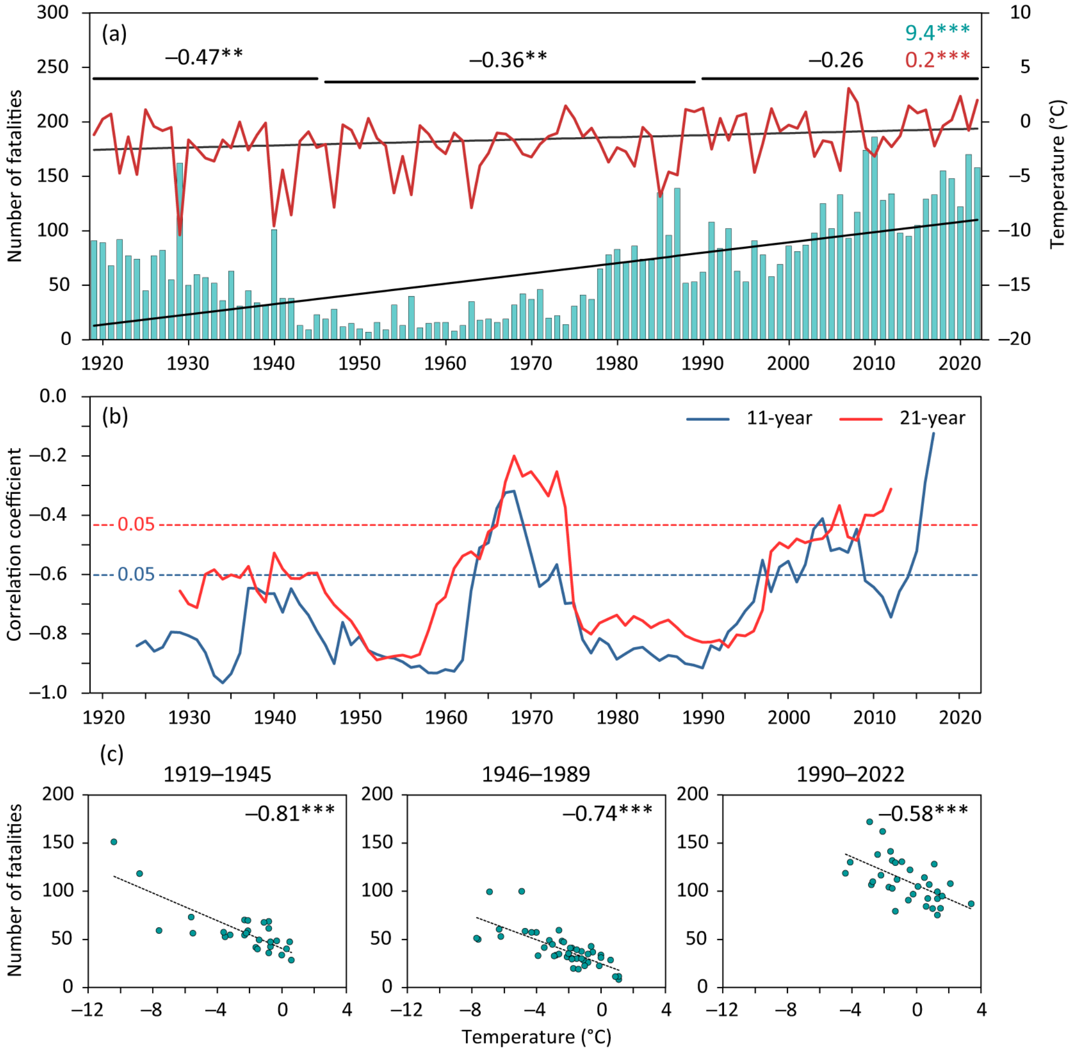


Figure 6. Numbers of fatalities related to excessive natural cold and mean January–February temperatures in the Czech Republic during the 1919–2022 period: (a) fluctuations, linear trends (right above slopes in fatalities/10 years and in °C/10 years) and Pearson correlation coefficients ($p < 0.05$, *** $p < 0.01$); (b) 11-year and 21-year running correlations between fatalities and temperatures (horizontal lines indicate significance levels for 0.05); (c) scatter-plots between detrended series of fatalities and temperatures for three selected periods (correlation coefficients right above, *** $p < 0.01$).**

The database of the CSO includes exact dates of deaths related to excessive natural cold from 1986, enabling an analysis of the relationship between the number of related fatalities and winter (December–February) temperatures from the 1986/87 to 2021/22 season. The three highest numbers of fatalities corresponded to the second coldest (1986/87) and the sixth-seventh coldest winters (2009/10, 2010/11) in this 36-year period. The linear trends showed a statistically significant increasing tendency in fatalities (13.3 fatalities/10 years, $p < 0.01$) and a non-significant increase of 0.4 °C/10 years in winter temperatures (Fig. 7a). The statistically significant Pearson correlation coefficient between both series is –0.46 ($p < 0.01$), which rises to –0.74 ($p < 0.01$) after detrending both series (for the related scatter-plot, see Fig. 7b).

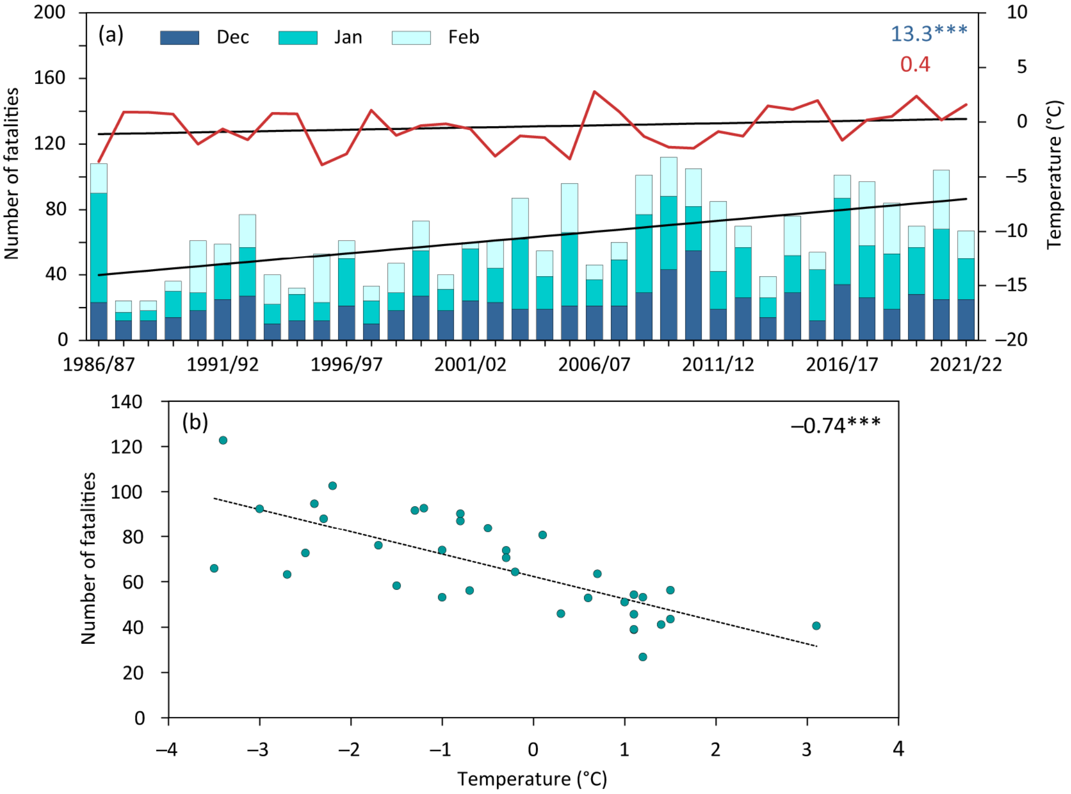


Figure 7. Numbers of winter fatalities related to excessive natural cold, divided according to individual months (Dec., Jan., Feb.), compared with winter (December–February) temperatures in the Czech Republic during the 1986–2022 period: (a) fluctuations and linear trends (right above slopes in fatalities/10 years and in °C/10 years; *** $p < 0.01$); (b) scatter-plot between detrended fatalities and winter temperatures (correlation coefficient right above, *** $p < 0.01$).

4.3.2 Lightning-related fatalities and thunderstorms

The fluctuations in annual numbers of lightning-related fatalities were compared with fluctuations in annual numbers of days with thunderstorms (expressed by median) across the CR for the 1919–2022 period (Sect. 2.3). As seen in Fig. 8, both series behave differently. The number of thunderstorm days shows, besides large inter-annual variability, a statistically significant decreasing linear trend of –0.4 days/10 years ($p < 0.01$), similar to the overall trend in the number of lightning fatalities (–4.6 fatalities/10 years, $p < 0.01$) (Fig. 8a). However, the fatalities exhibit two distinct phases: a steep decline from 1919 to 1972 (–8.2 fatalities/10 years, $p < 0.01$) and a slightly decreasing trend afterwards (–0.8 fatalities/10 years, $p < 0.01$). The statistically significant Pearson correlation coefficient between the fatality and thunderstorm series from 1919–2022 was 0.30 ($p < 0.01$), but non-significant for the two considered parts of the entire series (only 0.05 and 0.21, respectively). Non-significant 11-year and 21-year running correlation coefficients between lightning fatalities and the number of thunderstorm days prevailed throughout the 104-year period, with a few short time spans showing significant correlations (Fig. 8b). After detrending both series in the two aforementioned time intervals, the correlation coefficient increased to 0.34 ($p < 0.05$) for 1919–1972, but for the second interval, 1973–2022, it remained non-significant (0.16), slightly lower than the correlation from original values (0.21) (see scatter-plots in Fig. 8c).

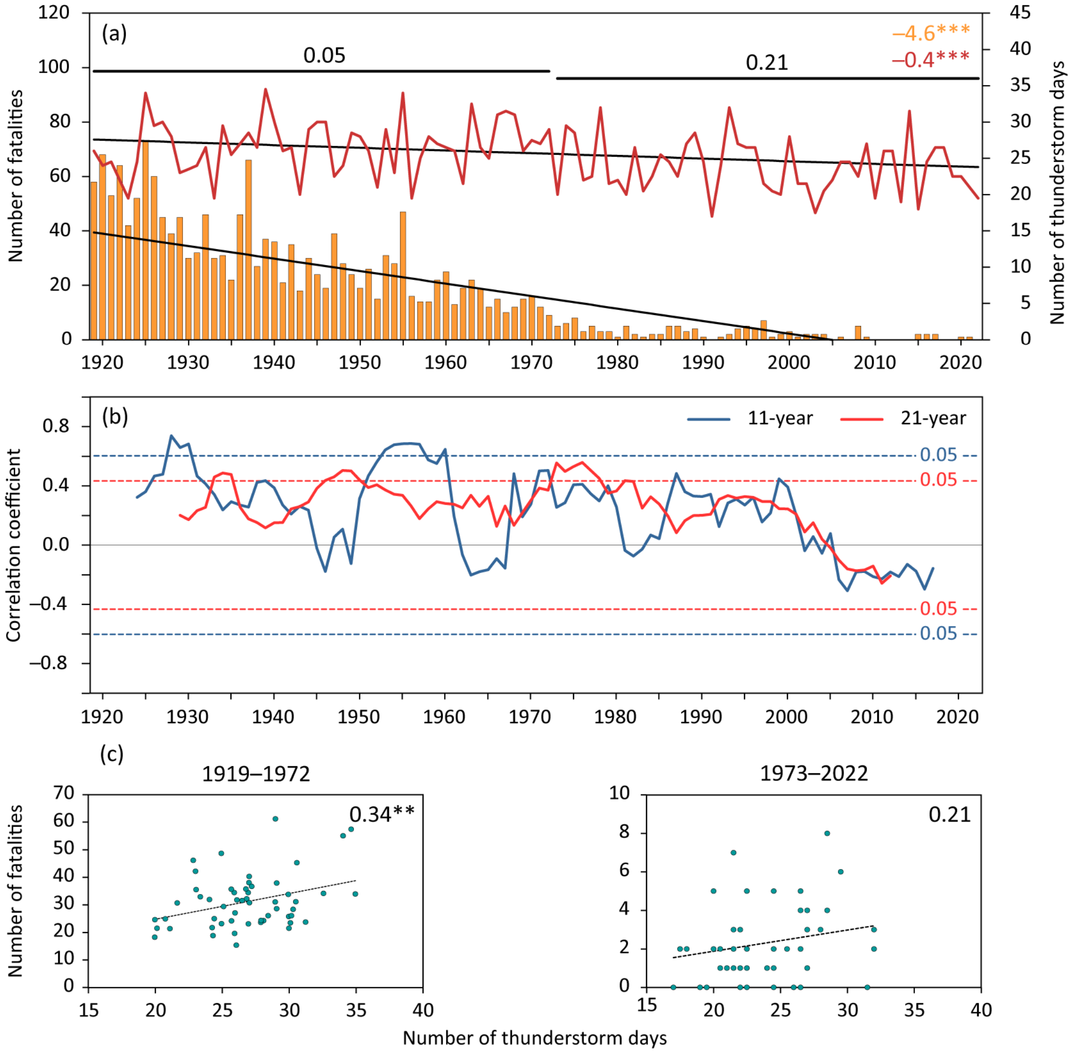


Figure 8. Annual numbers of fatalities related to lightning and days with thunderstorms (expressed by median) in the Czech Republic during the 1919–2022 period: (a) fluctuations, linear trends (right above; slopes in fatalities/10 years and days/10 years) and Pearson correlation coefficients (* $p < 0.01$); (b) 11-year and 21-year running correlations between fatalities and thunderstorm days (horizontal lines indicate significance level for 0.05); (c) scatter-plots between fatalities and thunderstorm days for two selected periods (1919–1972 – detrended values, 1973–2022 – original values; correlation coefficients right above, ** $p < 0.05$).**

5 Discussion

5.1 Data uncertainty

While demographic yearbooks are considered official and the most comprehensive source of fatality data in the CR, certain potential uncertainties relevant to this study must be acknowledged. The determination of the specific cause of death is based on a death certificate completed by a doctor according to the international list of diseases and causes of death (see Sect. 2.2) and their subjective judgment or evaluation. Even experienced healthcare professionals must choose from a wide range of possible causes of death, in which some categories (e.g., excessive natural heat, excessive solar radiation, non-specified natural forces) might be interpreted differently by individual doctors. Moreover, demographic yearbooks only include data concerning Czech citizens, thereby excluding deaths of non-Czechs within the CR (e.g., tourists, foreign workers) while including deaths of Czech citizens occurring abroad (e.g., nine fatalities in the category X34 Earthquakes during the 1994–2022 period). The number of weather-related fatalities may also have been affected by changes in the total population of the CR, which grew continuously from 9.922 million in 1919 to 11.160 million in 1940. A significant drop in population began especially after the transfer of Germans following World War II, with the total number decreasing to 10.693 million in 1945, 9.523 million in 1946, and reaching its lowest at 8.765 million in 1947. Subsequently, the population exceeded 9 million in 1951, 9.5 million in 1957, 10 million in 1975, and finally 10.5 million in 2010 (Český statistický úřad, 2023c).

5.2 A broader context of Czech weather-related fatalities

Fatalities attributed to excessive natural cold, particularly deaths due to freezing or hypothermia, were the most frequent severe weather victims in the CR during the 1919–2022 period (see Fig. 1). They exhibited a statistically significant increasing linear trend, despite the detected decreasing trend in the severity of winter temperatures and snow patterns in the CR from 1961 (Brázdil et al., 2023b). After a notable local maximum of fatalities in 1978–1987 (13.0 % of all these fatalities, mean rate 90.0 fatalities/year), their numbers dramatically increased in the last 20 years (2003–2022) to 37.5 % of such fatalities with a mean rate of 130.2 fatalities/year. The dominant part of cold-related fatalities was represented by males and those aged 65 years and older (for similar results see also Smith and Seridan, 2019 for the U.S. in 1975–2010). The reported dramatic fatality increase in recent decades in the CR could be partly explained by the increasing number of seniors ≥65 years, i.e., the age group most vulnerable to excessive natural cold (see Fig. 3), which may contribute to the related excess death as shown, for example, in the association between cold spells and daily mortality for 272 main cities in mainland China (He et al., 2023). The aging of the CR population is evidenced by the number of people aged ≥65 years during the study period. Their number increased from 0.621 million in 1920 to 0.846 million in 1939. After World War II, their number grew from 0.633 million in 1945 to 1.398 million in 1975, followed by a decline to 1.222 million in 1985 and some stagnation afterwards. From 2000, with 1.422 million seniors, there was a substantial increase to 2.160 million in 2022 (Český statistický úřad, 2023b). The potential relationship to cold-related fatalities was confirmed by high and statistically significant correlation coefficients between the numbers of fatalities and people aged ≥65 years (e.g., 0.64, $p < 0.01$ for 1920–2021 or 0.82, $p < 0.01$ for 1946–2021).

Another factor that could at least partly explain the increase in cold-related fatalities in the CR is the rise in the homeless population, which became more prominent particularly after the Velvet Revolution in 1989, while previously such individuals were rather rare. Although data on the homeless were not collected systematically, a 2011 survey reported 11,496 homeless individuals (Český statistický úřad, 2023d), and in 2019, the total reached 23,830 (Nešporová et al., 2019), nearly half of whom were living outdoors. While homeless individuals have the option to spend cold days and nights in special facilities, many prefer staying outdoors to avoid restrictions, such as alcohol prohibition. This exposure to low winter temperatures often leads to deaths from freezing or hypothermia. For instance, Romaszko et al. (2017) found that most deaths among the homeless in Olsztyn, Poland (2010–2016), occurred under conditions of cold stress, with hypothermia being thirteen times more common as a cause of death compared to the general population. Similarly, Lane et al. (2018) reported a significant proportion of unsheltered homeless affected by cold-related illness and death in New York City (the U.S.) during 2005–2014. Stickley et al. (2023) also highlighted the role of socioeconomically disadvantaged groups, including those with risky alcohol consumption and homelessness, in hypothermia mortality among individuals aged 30–74 years in the Baltic countries (Estonia, Latvia, Lithuania) and Finland during 2000–2015.

To account for these and other potential non-meteorological effects on cold-related mortality (see also Ekamper et al., 2010 for the Netherlands), the detrended Czech fatality series attributed to excessive natural cold demonstrated a close connection between the number of fatalities and low mean winter temperatures, expressed by statistically significant and very high negative correlation coefficients (see Sect. 4.3.1).

The increasing trend in cold-related fatalities in the CR aligns with the conclusion of Ryti et al. (2016), who stated that cold spells are associated with increased mortality rates globally, along with other adverse health effects. Conversely, Wang et al. (2016) projected a decrease in mortality related to cold waves for 209 U.S. cities from 1960 to 2050. Many other studies focusing on mortality due to cold spells, often covering shorter periods than our Czech study, provide less direct comparability. For example, Analitis et al. (2008) found that a 1 °C drop in minimum apparent temperature led to an increase in daily deaths due to natural causes (1.35 %), cardiovascular issues (1.72 %), respiratory problems (3.30 %), and cerebrovascular incidents (1.25 %), especially among older age groups, in 15 European cities from 1990–2000. Kyselý et al. (2009) observed a positive excess in cardiovascular mortality during cold spells in the CR from 1986–2006, with males aged 25–59 years being particularly at risk due to occupational exposure outdoors in winter. Orru and Åström (2017) reported higher mortality due to external causes on hot and cold days in Estonia from 1997–2013. Pascal et al. (2018) attributed 3.9 % of total mortality to cold temperatures in 18 French cities between 2000 and 2010. Plavcová and Urban (2020) noted an impact on excess mortality associated with sudden rises in minimum temperature and pressure drops during winter (3.7 % and 1.4 % respectively) in the CR from 1982–2017. Petkova et al. (2021) found that cold temperatures had a greater impact than hot temperatures on the elderly (≥65 years) in Sofia, Bulgaria, from 2000–2017, particularly under moderate and extreme cold conditions, with females being more vulnerable than males. Fonseca-Rodríguez et al. (2021) observed a smaller effect of cold winter weather on hospitalizations in Sweden from 1991–2014: cold and moist weather was linked to a delayed increase in cardiovascular hospitalizations, and together with cold and dry weather heightened the risk of respiratory disease hospitalizations. Fan et al. (2023) identified cold exposure as a critical risk factor for cardiovascular diseases, increasing mortality by 1.6 % for every 1 °C decrease, based on a review of 159 different studies. Interestingly, fatalities related to cold spells, unlike those attributed to heat waves, were not highlighted among weather-, climate-, and water-related fatalities in the World Meteorological Organization report (WMO, 2021). Masselot et al. (2023) found an annual excess of 203,620 deaths attributed to cold (compared to 20,173 attributed to heat) in 854 urban areas in Europe from 2000–2019, highlighting differing results across Europe and among age groups.

The significant decrease in lightning-related fatalities in the CR from 1919 to 2022, with a total of 1,786 deaths, highlights substantial changes in factors influencing these numbers. The decline is evident when comparing the fatality rate at the beginning and end of this 104-year period: 55.4 fatalities/year in 1919–1928 versus 0.8 fatalities/year in 2013–2022. This decreasing trend aligns with trends observed in the contiguous United States (López and Holle, 1998), where after a peak in the late 1910s–1930s, a steady decline in lightning deaths began from 1944 and continued until 1991. In the CR, male fatalities due to lightning clearly outnumber those of females, and the proportion of victims declines with age, peaking in the 15–24 year age group (cf. Fig. 3), a pattern similar to that observed in other countries (e.g., Raga et al., 2014 for Mexico, Singh and Singh, 2015 for India, Antonescu and Cărbunaru, 2018 for Romania). The annual number of lightning fatalities in the CR was significantly correlated with the annual number of thunderstorm days, but the correlation was relatively weak (see Sect. 4.3.2 and Fig. 8). While López and Holle (1998) noted parallel fluctuations in lightning deaths and nationwide changes in thunder-day frequencies in the United States from 1900–1991, they emphasized that thunder-day frequencies might not directly indicate lightning activity for a given year, and questioned the spatial representativeness of lightning activity over a large area based on point station observations.

Observing the statistically significant decreasing linear trend in lightning-related fatalities in the CR from 1919 to 2022 (cf. Fig. 1), it is necessary to consider some non-meteorological factors. This primarily includes changes in the proportion of people working in agriculture, a sector where exposure to thunderstorms outdoors or in open landscapes was more frequent (Elsom, 2001). In 1930, 2.316 million people were employed in this sector in the CR, and this number continuously decreased in subsequent decades: 1.588 million in 1946, 0.832 million in 1961, 0.578 million in 1981, 156,000 in 2001, and 133,000 in 2021 (Sálusová et al., 2003, updated). Additionally, the percentage of women in these totals decreased from approximately 59 % to 35 % between 1930 and 2021. For comparison, in the United Kingdom, deaths in the agricultural workforce due to lightning dropped from 38 % of all lightning fatalities around 1850 to 9 % by 2000 (Elsom, 2018). Other factors contributing to the decreasing trend in lightning-related fatalities include an increase in urban populations with predominantly indoor jobs, wider use of lightning conductors, improved weather forecasting, significant advancements in medical services, greater availability of immediate emergency assistance with rapid hospital transport, and increased public awareness of safety measures during thunderstorms (e.g., Curran et al., 2000; Elsom and Webb, 2014; Elsom, 2018; Brázdil et al., 2019).

In agreement with our study, Holle (2016) reported a significant reduction in lightning fatality rates for Western European countries and others transitioning from predominantly rural agricultural societies to primarily urban ones. In Switzerland, lightning fatalities dropped markedly between 1946–1980 and 1981–2015, with the annual mean lightning mortality rate declining from 0.7 to 0.14 fatalities per million people. Additionally, the first period had two years without lightning fatalities, which increased to 19 such years in the second period (Badoux et al., 2016). Elsom (2018) noted a dramatic decrease in the mean decadal lightning fatality rates for the United Kingdom, from 1.09 deaths per million inhabitants per year in the 1850s to 0.02 in the 2010s. The annual number of lightning fatalities in Romania decreased from 65 fatalities per year in 1999–2003 to 23.2 fatalities per year in 2011–2015 (Antonescu and Cărbunaru, 2018). A declining trend in lightning fatalities over recent decades has been confirmed in other countries as well (e.g., Mills, 2020 for Canada). Conversely, the number of lightning fatalities in China increased between 1997 and 2007, then started to decrease since 2008 (Zhang et al., 2011). Singh and Singh (2015) reported an increase in lightning fatalities in India from 1979 to 2006 and a subsequent decrease from 2007 to 2011. Other papers presenting detailed analyses of lightning fatalities did not report any trends, mainly due to incomplete datasets or short time series (e.g., Tilev-Tanriover et al., 2015 for Turkey, and Holle et al., 2019 for Bangladesh). Pilorz et al. (2023) mentioned 151 lightning-related fatalities in Central Europe from 2010–2020, averaging 13.7 fatalities per year, but it is unclear if all seven fatalities reported in the Czech CSO database for 2010–2020 were included.

Regarding fatalities attributed to excessive natural heat, their numbers in demographic yearbooks were significantly underestimated (see Table 3, Figs. 1 and 4). In the CR during 1919–1948, with a mean summer temperature of 15.9 °C, a total of 224 fatalities were recorded. However, in the period from 1993–2022, when summers were warmer by 2 °C, only 47 fatalities were documented. Although the number of fatalities for 1986–2022 (cf. Fig. 4) showed a slightly increasing linear trend, these numbers are considerably lower than those reported in other studies analyzing heat-wave event fatalities in the CR in individual years (e.g., Kyselý and Kříž, 2008; Knobová et al., 2014; Urban et al., 2017; Arsenović et al., 2019) or over longer periods (e.g., Kyselý and Plavcová, 2012; Hanzlíková et al., 2015; Urban et al., 2020, 2022). This indicates that fatalities related to excessive natural heat in demographic yearbooks were likely classified under other disease/cause categories according to the international list and do not reflect the actual numbers. A similar situation is observed with fatalities caused by natural hazards~~disasters~~, as evident from a comparison with data in Brázdil et al. (2023a). For instance, the 126 fatalities reported in Czech demographic yearbooks (1931–2020) constitute only 21.0 % of the 600 fatalities reported in the cited study.

The numbers of weather-related fatalities from demographic yearbooks can be partially compared with those in a specific fatality database of the Institute of Geography, Masaryk University, Brno (IGMU), primarily compiled from documentary evidence (mainly newspapers) and used by Brázdil et al. (2023a) for their study of weather-related fatalities in the CR during the 1921–2020 period. As expected, the IGMU database covers only a smaller percentage of the fatalities reported in CSO data: 22.4 % for lightning fatalities, 13.3 % for falls on ice or snow (1994–2020), 11.8 % for excessive natural cold, and 8.6 % for excessive natural heat. However, the situation is reversed for natural hazards~~disaster~~ fatalities (as mentioned earlier). Additionally, the IGMU database facilitates spatiotemporal analysis of individual fatal events, including specific characteristics of the fatalities, which are either entirely missing or only partly covered in demographic yearbooks or the CSO database. These include the exact day (or part of the day) and location of the death, the type of death (direct or indirect), the cause and place of death, or the victim's behavior (hazardous or non-hazardous). Furthermore, fatalities in the IGMU database can be attributed to specific weather/hydrometeorological events like floods, windstorms, convective storms, fog, etc. Such additional data are crucial for a comprehensive understanding of the circumstances leading to the loss of human lives during severe weather situations, with significant implications for risk management.

6 Conclusion

From the analysis of weather-related fatality data published by the CSO in the demographic yearbooks for the CR covering the period 1919–2022, the following conclusions can be summarized:

(i) Czech demographic yearbooks provide official figures, including gender and age, for weather-related fatalities attributed to excessive natural cold, excessive natural heat, lightning, natural hazards~~disasters~~, air pressure changes, and falls on ice or snow for the CR during the period 1919–2022 or parts thereof. Based on death certificates and international lists of death causes, these yearbooks undervalue fatalities attributed to extreme natural heat, natural hazards~~disasters~~, and air pressure changes, but are representative for the three remaining categories. The proportion of weather-related fatalities to the total number of deaths in the CR annually fluctuated only between 0.2 ‰ (in 1974) and 1.7 ‰ (in 2009).

(ii) The average annual rate of 89 weather-related fatalities during 1919–2022 comprised 74.9 % from excessive natural cold and 19.3 % from lightning. Despite significant temporal fluctuations, statistically significant increasing linear trends were observed in the numbers of deaths due to excessive natural cold, excessive natural heat, and falls on ice or snow, while a decreasing trend was noted in lightning fatalities. Males and seniors aged ≥65 years were the most affected gender and age groups, respectively. Only in lightning fatalities did the age group 15–24 years outnumber the seniors.

(iii) Fatalities due to excessive natural cold showed a negative correlation with mean winter month temperatures (i.e., lower temperatures mean higher fatality numbers). This statistically significant correlation has been declining since 1919, with alternating periods of lower and higher correlations. The dramatic increase in related fatalities in the past 20 years, accounting for 37.5 % of the total number in this category, indicates the increasing vulnerability of the aging population and homeless to cold episodes. The detrended series showed a statistically significant and very close relationship between fatalities and winter temperatures.

(iv) The number of lightning fatalities was statistically significantly and positively correlated with the mean annual number of days with a thunderstorm (i.e., more thunderstorms contribute to higher fatality numbers), but the correlation is relatively weak. A dominant proportion of fatalities, with a strong decreasing trend from 1919 to 1975 (94.6 % of all lightning fatalities), clearly demonstrated the effects of a significant reduction in the number of people employed in agriculture, changes in lifestyle, and improved medical care.

(v) The demographic yearbooks provide the most comprehensive information on the numbers, gender, and age of fatalities attributed to excessive natural cold, lightning, and falls on ice or snow in the CR. However, they are insufficient for studying other circumstances and characteristics of such weather-related fatal events, as well as for distinguishing fatalities caused by other severe weather events. This underscores the importance of other existing or specially created databases for in-depth investigation of such fatal events and the use of related knowledge in risk management to save lives endangered by weather extremes.

Appendix A

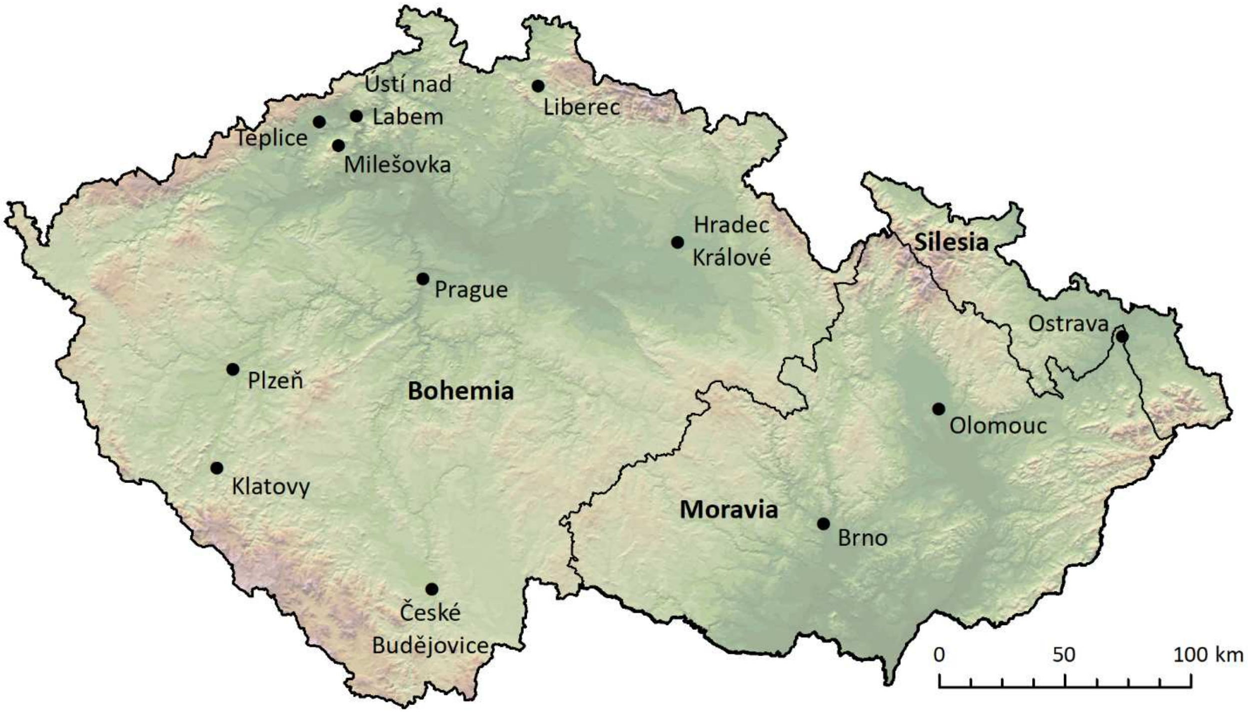


Figure A1. Locations in the Czech Republic mentioned in this paper (data source: ArcCR 500 v2.0).

Data availability. Meteorological data (temperatures and thunderstorm days) can be made available by the authors upon request. Fatality and other demographic data of the Czech Statistical Office can be found in the related published yearbooks (Český statistický úřad, 2023a, 2023b, 2023c, 2023d) or by the Czech Statistical Office upon request.

Author contributions. RB extracted data from yearbooks, proposed statistical analyses, designed and wrote the paper with contributions from two co-authors. KC extracted data from yearbooks, created the fatality database and made basic analyses, including finalizing of figures. PZ prepared meteorological data and contributed with statistical analyses of relationships between fatalities and meteorological factors.

Competing interests. The authors declare that they have no conflict of interests.

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