Patterns of extreme temperature-related catastrophic events in Europe including the Russian Federation: a cross-sectional analysis of the Emergency Events Database

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ABSTRACT

Objective To investigate reported extreme temperature-related catastrophic events and associated mortality on the European continent including the Russian Federation.

Design Cross-sectional respecting Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria.

Settings Data source: Emergency Events Database (EM-DAT).

Participants Search criteria: location—European continent including Russia, time—years 1988 to 2019 (close of database 12 July 2019), catastrophic events—extreme temperatures.

Primary outcome measures Numbers of heat waves, cold waves, severe winter conditions and associated number of deaths, overall, and per country and year, respecting STROBE criteria.

Results The most frequent type of the 243 events recorded in EM-DAT were cold waves (54.7%). However, cold waves and severe winter conditions only accounted for 6460 deaths (4.5%), while heat waves were associated with 137533 deaths (95.5%). The five most severe heat waves in 2003, 2006, 2010, 2013 and 2015 were associated with a total of 135089 deaths. The most severe heat waves were geographically distributed over the Russian Federation (2010), as well as France, Italy, Spain and Germany, each in 2003.

Conclusion Although cold waves are more frequently reported in EM-DAT, heat waves are the major cause for temperature-related deaths. In order to better protect the public, it is important to address resiliency and vulnerability of populations at risk and age groups.

INTRODUCTION

In total 18 out of 19 of the hottest summers on record occurred after 2001, with 2016 marked by the warmest summer so far. As climate experts expect this trend to progress, periods of extreme heat and cold could become more frequent in the future. Exposure of humans to extreme temperatures causes a considerable danger to health. The average human body temperature is defined as 36°C to 37.5°C. A deviation of ±3°C can overexert the body’s compensation mechanisms and cause substantial damage, potentially leading to death. Population groups such as the elderly and people with chronic (respiratory) diseases have a particularly high risk of being affected by extreme temperatures due to exhaustion of predominantly cardiorespiratory compensatory mechanisms. However, the extent to which extreme temperatures affect humans is subject to complex biological, regional, geographical and social factors.

Children have been previously identified as a vulnerable group for heat-related mortality. One report covering observations in Budapest, London and Milan, from 1933 to 2001, 1993 to 2003 and 1999 to 2004, respectively, shows that between 0.8% and 1.4% of deaths due to heat waves were children under 14 years of age. Xu et al concluded that children under 1 year of age are particularly vulnerable to heat-related deaths. Both hot and cold weather influenced paediatric infectious diseases, for example, gastrointestinal or respiratory diseases and...
heat waves were associated with a higher incidence in renal disease, fever, and electrolyte imbalances.

In addition, excessive heat has been linked to considerable negative effects on mental health; it has been shown to increase psychiatric hospitalisation rates and prevalence of psychiatric disorders, predominately depressive disorders, anxiety, insomnia and substance use disorders, but also aggressive behaviours. Yet, the development of a psychiatric disorder after experiencing a (natural) disaster does not occur by default in all individuals. This can be attributed to the construct of resilience, which describes the ability to overcome adverse situations without long-term negative effects.

Despite the great danger posed by extreme temperature situations, the public seems to be insufficiently aware of this problem. A comprehensive civil protection survey from 2009, conducted in 27 European countries with 26,470 interviews listed flooding (45%), violent storms (40%) and industrial accidents (29%) as the three most feared disasters; heat waves were not mentioned at all. It is important to render the occurrence of extreme temperatures and associated mortality transparent. We, therefore, directed our efforts in analysing temperature-related catastrophic events and associated mortality on the European continent including the Russian Federation between 1988 and 2019 in order to derive measures for a competent handling of the health hazard caused by temperature extremes.

METHODS

Data source

This is a cross-sectional study. Ethics approval was not required, because this study does not directly involve human research. Similar to a previous epidemiological study of disasters in Germany and France, the present data analysis based on Emergency Events Database (EM-DAT), launched in 1988, maintained by the Centre for Research on the Epidemiology of Disasters at the School of Public Health of the Université catholique de Louvain located in Brussels, Belgium. EM-DAT is a humanitarian database and captures data on more than 21,000 disasters that occurred worldwide between 1900 and today. Disaster classification in EM-DAT is based on and adapted from the Integrated Risk Assessment of Disaster Peril Classification and Hazard Glossary. As such, ‘extreme temperature’ is defined as ‘a general term for temperature variations above (extreme heat) or below (extreme cold) normal conditions’. A ‘heat wave’ is defined as ‘a period of abnormally hot and/or unusually humid weather’, whereas a cold wave is defined as ‘a period of abnormally cold weather’. Both weather extremes typically last two or more days. Severe winter conditions include snow, ice, frost and freeze. The exact temperature criteria for what constitutes a heat or cold wave varies by location. Data sources for EM-DAT are UN agencies, governments, the International Federation of Red Cross and Red Crescent Societies, other non-governmental organisations, insurance companies, research institutes and press agencies. For inclusion of a disaster in the EM-DAT, one or more of the following criteria must be fulfilled: (1) 10 or more people dead, (2) 100 or more people affected, (3) the declaration of a state of emergency or (4) a call for international assistance. A detailed description of the EM-DAT including structure, classification, variable descriptions and definitions is available here: https://www.emdat.be/guidelines.

Data query

EM-DAT was accessed over the internet on 10 July 2019. The following advanced search parameters were applied: period: 1988–2019; location: continent ‘Europe’ (as referenced by EM-DAT, this includes the Russian Federation, which has a European and an Asian part); disasters classification: meteorological—extreme temperature (cold wave, heat wave, severe winter conditions). The following variables were extracted and analysed: catastrophic event start date, end date, country, disaster type, disaster subtype, total deaths, temperature magnitudes. The queried data set was transmitted to MR as validated data through email by EM-DAT on 12 July 2019. The last database update was 19 April 2019. Data were manually checked for plausibility. Two

Figure 1  (A) Reported temperature-associated deaths in Europe for heat waves and cold weather (cold wave/severe winter conditions) between 1988 and 2019. Horizontal lines indicate medians, p<0.0001 (Mann-Whitney U test). * designates events in the Russian Federation. Heatmap of total deaths associated with extreme temperature (B) heat waves and (C) cold weather, that is, cold wave/severe winter conditions) throughout the European continent including the Russian Federation reported in the Emergency Events Database between 1988 and 2019.
hundred and forty-three events fulfilling the above criteria were reported, none of these events were filtered out. Missing data were not imputed. Temperature magnitudes were not reported for 125 out of 243 (51%) events, deaths were not reported for 45 out of 243 (19%) events. Duration of an event was calculated as the difference between start date and end date. If the dates were reported in EM-DAT with a daily precision, duration was calculated in days. If dates were reported in EM-DAT with a monthly precision (ie, day of start or day of end was missing), duration was calculated in months assuming the whole month was affected by the event. For geographical mapping (figure 1) events were attributed to the precise regional location according to current geographical jurisdictions (eg, ‘German Federal Republic—DFR’ was recoded to ‘Germany—DEU’). Data for population size of countries for a given year were retrieved from https://www.worldometers.info/world-population/population-by-country/ (Dover, Delaware, USA, accessed 13 March 2020).

Endpoints
Endpoints of this study were numbers of heat waves, cold waves and severe winter conditions and associated number of deaths (overall, and per country and year).

Statistical analysis
Strengthening the Reporting of Observational Studies in Epidemiology criteria, a quality assurance reporting guideline and checklist for observational studies, were respected.25 Standard methods of descriptive statistics were applied. Variables were summarised using counts and percentages of the total study population. Differences between deaths associated with heat waves versus cold waves/severe winter conditions were calculated

Table 1 Reported catastrophic heat waves with more than 100 deaths on the European continent including the Russian Federation by country, year, duration and temperature magnitude between 1988 and 2019 in descending order by absolute number of deaths

| Country | Year | Duration* | Temperature magnitude value (°C)† | Deaths | Population size | Deaths per 100 000 inhabitants |
|---------|------|-----------|-----------------------------------|--------|----------------|-------------------------------|
| Russia  | 2010 | 3 months  | 40                                | 55736  | 143 479 274    | 38.8                          |
| Italy   | 2003 | 30 days   |                                    | 20 089 | 57 564 588     | 34.9                          |
| France  | 2003 | 19 days   | 43                                | 19 490 | 60 251 588     | 32.3                          |
| Spain   | 2003 | 10 days   | 40                                | 15 090 | 42 566 453     | 35.4                          |
| Germany | 2003 | 1 month   |                                    | 9 355  | 81 614 380     | 11.5                          |
| France  | 2015 | 41 days   | 40                                | 3 275  | 64 453 200     | 5.1                           |
| Portugal| 2003 | 1 month   |                                    | 2 696  | 10 429 612     | 25.8                          |
| France  | 2006 | 8 days    | 37                                | 1 388  | 61 508 926     | 2.3                           |
| Belgium | 2003 | 14 days   |                                    | 1 175  | 10 419 032     | 11.3                          |
| Switzerland | 2003 | 1 month |                                    | 1 039  | 7 268 359     | 14.3                          |
| Netherlands | 2006 | 8 days   |                                    | 1 000  | 16 440 097     | 6.1                           |
| Netherlands | 2003 | 13 days  |                                    | 965   | 16 200 951     | 6                             |
| Belgium | 2006 | 2 months  |                                    | 940   | 10 619 475     | 8.9                           |
| Croatia | 2003 | 1 month   |                                    | 788   | 4 388 895      | 18                            |
| UK      | 2013 | 1 month   |                                    | 760   | 64 984 018     | 1.2                           |
| Hungary | 2007 | 1 month   | 41.9                              | 500   | 10 024 149     | 5                             |
| Portugal| 2005 | 3 months  |                                    | 462   | 10 508 495     | 4.4                           |
| Czechia | 2003 | 1 month   |                                    | 418   | 10 239 136     | 4.1                           |
| Belgium | 2015 | 5 days    |                                    | 410   | 11 287 940     | 3.6                           |
| Austria | 2003 | 2 months  |                                    | 345   | 8 175 852      | 4.2                           |
| UK     | 2003 | 1 month   |                                    | 301   | 59 561 432     | 0.5                           |
| Slovenia| 2003 | 2 months  |                                    | 289   | 1 987 862      | 14.5                          |
| Russia | 2001 | 1 month   | 30                                | 276   | 14 583 072     | 0.2                           |
| Luxembourg | 2003 | 1 month |                                    | 170   | 447 322        | 38                             |

*Duration was calculated as the difference between start date and end date. If the dates were reported in the Emergency Events Database (EM-DAT) with a daily precision, duration was calculated in days. If dates were reported in EM-DAT with a monthly precision, duration was calculated in months assuming the whole month was affected by the event.
†Missing values indicate that no data were reported to EM-DAT.
with the Mann-Whitney U test. A two-sided p value of equal or less than 0.05 was considered statistically
significant. Statistical analysis and graphics including
the spinogram were conducted with GraphPad Prism
5.04 (La Jolla, California, USA), and R (http://www.r-project.org). The European map was plotted using
the R extension ‘ggmap’.26

**Patient and public involvement statement**

Patients and the public were not involved in this study.

**Limitations**

The analysis of EM-DAT has some important limita-
tions that have to be taken into account for the
appropriate interpretation of the findings presented
below.22 The analysis relies on the accuracy of the
reported data. Original source data verification was
logistically not feasible and was, therefore, not under-
taken. Epidemiological surveillance in individual
single country included in the present analysis may
vary leading to data heterogeneity. The definition of
extreme temperatures, including heat and cold waves,
may vary locally which could lead to ascertainment
bias.24 Assuming that a full month was affected when
the start and end dates in EM-DAT were reported with
a precision to the month only (tables 1 and 2) may
overestimate the duration of events. Data in EM-DAT
are not stratified by age, gender or social factors such
as income levels, which would allow a more detailed
analysis of vulnerable populations including children
and facilitate better data-driven paediatric decision-
making in catastrophic situations in the future.
Depending on the precise research question, addi-
tional data may be gathered from other providers in
the future. Nevertheless, EM-DAT is an authoritative
state-of-the-art data source.22

**RESULTS**

**Overall temperature-associated disaster pattern in Europe and the Russian Federation**

Since 1988, 243 disasters associated with extreme
temperatures were reported in Europe and the Russian

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| Table 2 | Reported catastrophic cold waves and severe winter conditions with more than 100 deaths on the European continent including the Russian Federation by country, year, duration, disaster subtype and temperature magnitude between 1988 and 2019 in descending order by absolute number of deaths |
|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| Country | Year | Duration* | Disaster subtype | Temperature magnitude value (°C)† | Deaths | Population size | Deaths per 100,000 inhabitants |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| Ukraine | 2006 | 21 days | Severe winter conditions | −30 | 801 | 46 607 395 | 1.7 |
| Russia | 2001 | 1 month | Cold wave | −26 | 332 | 145 830 721 | 0.2 |
| Poland | 2009 | 86 days | Cold wave | −35 | 298 | 38 351 916 | 0.8 |
| Poland | 2001 | 102 days | Cold wave | −25 | 270 | 38 529 582 | 0.7 |
| Russia | 2002 | 1 month | Cold wave | −50 | 242 | 145 215 700 | 0.2 |
| Russia | 2000 | 1 day | Cold wave | −7 | 232 | 146 404 903 | 0.2 |
| Russia | 1995 | 1 day | Cold wave | −20 | 208 | 148 227 466 | 0.1 |
| Poland | 2010 | 4 months | Cold wave | −33 | 200 | 38 329 781 | 0.5 |
| Poland | 2005 | 5 months | Severe winter conditions | −32 | 191 | 38 368 949 | 0.5 |
| Poland | 2002 | 4 months | Cold wave | −25 | 183 | 38 488 647 | 0.5 |
| Poland | 2012 | 20 days | Cold wave | −27 | 177 | 38 227 044 | 0.5 |
| Russia | 2012 | 11 days | Cold wave | −7 | 170 | 143 993 892 | 0.1 |
| Russia | 1999 | 1 month | Cold wave | −27 | 162 | 146 915 915 | 0.1 |
| Poland | 1999 | 1 month | Cold wave | −27 | 154 | 38 567 854 | 0.4 |
| Russia | 2001 | 2 months | Cold wave | −57 | 145 | 145 830 721 | 0.1 |
| Slovakia | 2010 | 4 months | Cold wave | −32 | 122 | 539 867 | 2.3 |
| Russia | 2006 | 1 month | Severe winter conditions | −43 | 116 | 143 403 256 | 0.1 |
| Ukraine | 2012 | 1 month | Cold wave | −30 | 112 | 45 453 806 | 0.2 |

*Duration was calculated as the difference between start date and end date. If the dates were reported in the Emergency Events Database (EM-DAT) with a daily precision, duration was calculated in days. If dates were reported in EM-DAT with a monthly precision, duration was calculated in months assuming the whole month was affected by the event.

†Missing values indicate that no data were reported to EM-DAT.
Federation. Catastrophic events associated with cold were more frequently reported than events associated with hot temperatures. There were 133 (54.7%) events associated with cold waves, 41 (16.9%) events due to severe winter conditions and 69 (28.4%) catastrophic events associated with heat waves. Overall, these disasters resulted in 143993 deaths. Catastrophic heat waves were associated with 137533 (95.5%) deaths. Catastrophic events due to cold waves were associated with 4983 (3.5%) deaths and severe winter conditions resulted in the death of 1477 (1%) people. The difference between deaths associated with hot extreme temperatures versus cold extreme temperatures (cold waves plus severe winter conditions) was statistically significant (p<0.0001, Mann-Whitney U test, figure 1A). Geographical mapping reveals the distribution of extreme weather-related events that led to high numbers of deaths throughout Europe (figure 1B,C, number of total deaths associated with cold and heat). For both, heat-related and cold-related events, the Russian Federation was among the countries with high numbers of reported deaths. Heat-related deaths were primarily reported in central-southern European countries, only little data were reported for northern European countries.

In the 32 years from 1988 to 2019, a median of 4 (IQR 2–12) events occurred per year, most catastrophic events occurred in 2012 (39=16%), 2005 (21=8.6%), 2010 (19=7.8%), 2009 (17=7%) and 2006 (17=7%). The overall distribution of event frequency for heat waves, cold waves and severe winter conditions over time is shown in figure 2. It is also important to note that during the period 2005–2010 the highest number of events was recorded in EM-DAT (n=68). Since 1988, the creation of EM-DAT, the 5 years with most reported deaths due to heat waves in Europe were 2003 (72210 deaths), 2006 (3418 deaths), 2010 (55 736 deaths), 2013 (760 deaths) and 2015 (3685 deaths). In contrast, the 5 years with the highest number of reported deaths due to cold weather were 2001 (894 deaths), 2002 (435 deaths), 2006 (1077 deaths), 2010 (429 deaths) and 2012 (1056 deaths). Catastrophic heat waves and catastrophic cold waves including severe winter conditions on the European continent including the Russian Federation associated with more than 100 deaths since 1988 are listed in tables 1 and 2.

**DISCUSSION**

The present data suggest that heat waves in particular are a public health threat for the population on the European continent including the Russian Federation. Although less frequently reported than cold waves, heat waves were associated with significantly more deaths than cold temperature extremes. Considering the resilience of individuals to extreme temperature fluctuations, the body’s own ability to acclimatise plays an important role. Research has shown that in addition to the length and intensity of heat waves, their occurrence over the course of the year has an impact on mortality. Early heat waves
were associated with higher mortality rates. This could be explained, for example, by a lack of preceding acclimatisation. Putting humans and the results of this study in a more general evolutionary perspective, heat resilience evolved already in early members of the genus *Homo*, when the body’s ability to adapt its metabolism according to surrounding temperature emerged to represent a major advantage. *Homo sapiens* originated in the hot climates of Africa between 300 000–200 000 years ago with a typical linear physique indicative of heat-related adaptations, and dispersed to the more temperate climates of Eurasia only by ca. 60 000–40 000 years ago. Tolerance towards cold in our species since the Palaeolithic appears to have been mostly dependent on behavioural support, evidenced in the archaeological record for example by specialised cold weather clothing and fire making. The generally increasing reliance on cultural buffers in the recent evolution of our species likely lead to a general relaxation of selection pressures on anatomical, genetic and physiological adaptations to cope with extreme cold or heat.

The 2009 European survey in which heat waves were not mentioned at all as a feared disaster is remarkable given the known risks of heat waves and their substantial impact on the population, in particular in Europe during the year 2003. This may not be surprising, because, unlike flooding, violent storms and industrial accidents, heat waves are not visually dramatic—people die quietly in overheated homes and apartments. Therefore, public health researchers need to work on and can make a difference with effective messaging to let the public know that heat waves can kill silently. There are excellent examples for comprehensive heat mitigation strategies and communication plans in order to protect vulnerable groups, including the elderly, children under 4 years of age, pregnant women, people with certain chronic medical or psychiatric conditions, patients undergoing certain pharmacological treatments, the poor, the frail, but also athletes and outside workers. The French Republic has a comprehensive national heat plan elaborated by the French Ministry of Health and Solidarity, the public health system, and Météo France, the national weather agency. The plan comprises four escalating color-coded regional meteorological surveillance alert levels and four lines of action, that is, (1) prevention, (2) protection, (3) communication and (4) improvement by learning. The plan is usually activated during the vulnerable summer period between 1 June and 31 August each year. As a positive and very instructive example of intuitive public health communication, France uses a nationally aligned, visually enhanced public health advertising campaign to clearly communicate heat risks and mitigation measures to the public. This includes easy-to-understand messages such as ‘drink water and keep cool’, and ‘avoid alcohol, eat sufficiently, keep blinds and shutters closed during the day, leave your window open at night, spray yourself with water and keep in touch with friends and family’. French public health advertising includes messaging to the general public and specific focus groups including workers and employers, athletes and childcare facilities, in addition to practical advice for the public on how to handle cooling technology. As another direct consequence of the 2003 heat wave, air condition systems were installed in French nursing homes in order to protect older citizens. Other examples for instructive heat wave mitigation strategies include the ‘Heatwave Guide for Cities’ developed by the Red Cross Red Crescent Climate Centre and the ‘beat the heat’ campaign of the New South Wales Ministry of Health in Australia. Possible paediatric mitigation strategies are presented in table 3.

Deaths due to extreme temperatures reported to EM-DAT include excess mortality compared with...
previous years for all causes of death and not only external causes such as hyperthermia or heat strokes. A study by Berko et al. analysed deaths due to external causes associated with heat, cold and other weather events in the USA and found, in general, more deaths being associated with cold (63%) than with heat (31%), although there was some regional variability. It is possible that the methodological focus on external causes of heat (hyperthermia) and cold (hypothermia) exposures may underestimate the overall mortality of heat and cold waves, in particular the impact of heat waves.

Maybe public perception of heat risk is low in part because people often associate heat waves with dehydration and heat stroke, when in reality, heat exacerbates cardiovascular, respiratory and other pre-existing conditions.

We consider the present findings generalisable within the context of the important limitations outlined in the methods section. Given the data in this report and the fact that temperature-related injuries are preventable, it is important to educate the European public about the danger of heat waves in order to appropriately (1) prevent, (2) respond to and (3) recover well from heat-associated disasters.

CONCLUSIONS

Although cold waves are more frequently reported in EM-DAT, heat waves were the major cause of temperature-related deaths in Europe and the Russian Federation. In order to better protect the public, it is important to address resiliency and vulnerability of at-risk populations and age groups.

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Contributors

HB and MR developed the concept of the study and formulated hypotheses. HB, MR, ER, and SG organised and analysed the data. SG performed all statistical analyses. HB, MW, KM, SG, and MR helped interpreting the results. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Map disclaimer

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All data relevant to the study are included in the article.

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