Spatial and sociodemographic heterogeneities in climate-related mortality: a systematic literature review

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Background: Motivation for research

The Summer of 2023 continued to set new precedents; the June to August period was the warmest on record in both the northern and southern hemisphere, their highest since the National Oceanic and Atmospheric Administration (NOAA) started measuring 174 years ago (NOAA, 2023). The study of the association between extreme temperatures and mortality has been widely studied, notably since the heat wave of August 2003 in Europe, which led to over 70,000 excess deaths across 16 European countries (Robine et al., 2008). These temperature extremes have been accompanied by a continual increase in frequency and mortality risk of natural hazards i.e., floods, storms, drought, wildfire in recent years (Centre for Research on the Epidemiology of Disasters (CRED), 2015; Kharb et al., 2022).

This association has principally been studied in the European and North American contexts (Borrell et al., 2006; Gasparrini et al., 2022; Martinez et al., 2018; Masselot et al., 2023). The temperature mortality curve is complex; in most climate zones it takes the shape of a U or reversed J, where mortality is heightened at both extremes. In Europe extreme cold poses a greater mortality risk than extreme heat (Masselot et al., 2023). However, in South Asia, a statistically significant association between temperature and increasing mortality was observed only at high ambient temperatures (Dimitrova et al., 2021). Adverse temperature effects on population health were found to vary by demographic, socioeconomic, and geographic characteristics. The European study identified heterogeneity in socioeconomic and environmental conditions as an effect modifier of mortality risk (Masselot et al., 2023).

Despite the consensus that sociodemographic determinants affect heat- and cold-related mortality, the evidence and direction of the effects for some variables varies considerably between studies and regions (Borrell et al., 2006; Dimitrova et al., 2021; Son et al., 2019). For instance, while one literature review report that women have a lower risk of heat-related illness than men (Gifford et al., 2019), other reviews of evidence indicate that the risk of heat-related mortality risk is higher for women (Son et al., 2019; Van et al., 2019). This inconsistency complicates the development of risk mitigation policies aimed at vulnerable population subgroups.

Identifying patterns and trends as well as assessing inconsistencies in research findings through systematic literature review help strengthen our understanding of how populations and their vulnerability to extreme temperatures and natural hazards differ or share similarity. This systematic literature view thus aims to synthesize existing evidence on climate-related mortality across climatic hazards, geographic regions and sociodemographic characteristics including sex, age, education, and place of residence. By providing a robust synthesis of existing knowledge, the research findings can contribute to evidence-based public health policy design; providing planned interventions, that consider sociodemographic diversity and regional nuances.

Method: *search strategy and study selection*

A systematic literature review was performed, following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Date restriction was applied in the search WebofScience. This was to identify observational studies investigating the relationship between extreme temperature, natural hazards, and mortality. The search terms included “climate change”, “weather”, “atmospheric pressure”, “global warming”, “climate disaster”, “flood”, “storm”, “cold”, “heat” “fire”, “hurricane”, “temperature”, “drought” and “mortality”, “death”, “years of life lost (YLL)” in various permutations and combinations, modelled from search terms used in a review and meta-analysis of climate extremes in the South Asian context from Dimitrova *et al.*, (2021).

Inclusion of only quantitative observational studies, indiscriminate of location. **Outcome measures** include mortality counts, life expectancy, years of life lost or risk ratios. Studies investigating morbidity were excluded, as well as those that include the effect of air pollution, through wildfire or other indirect causes. No restrictions were placed on duration of exposure in studies screened. A combination of these factors determined the relevancy of the articles, based on the information provided in the Title and Abstract fields. Initially, 3,376 records were screened using software AS Review (https://asreview.readthedocs.io). A total of 466 articles were selected from the first screening; 430 articles were retrieved for temperature-related mortality (193 referring to “hot” or “heat”, 54 referring to “cold” in article titles; **Table 1**) and 36 for natural hazard-related mortality. These articles provide evidence across world regions **(Figure 1)**. Regional breakdown of study locations includes Africa (11), Americas (41; including 25 from the USA), Asia (142; including 81 from China), Europe (107), Oceania (10). Further screenings will be conducted, focusing on quantitative measures, from which a meta-analysis of the literature will be performed.

Descriptor of Interest	**Count**	**Descriptor of Interest**	**Count**
Temperature:		*Hazard:*	
“Hot” or “Heat”	193	“Hurricane”	10
“Cold”	54	“Drought”	9
“Ambient”	40	“Flood”	8
“Weather”	23	“Disaster”	3

Table 1: Figure 1: Occurrence of selected descriptor fields specified across 466 article titles, selected during first systematic review screening e.g., “cold”, “Cold”.

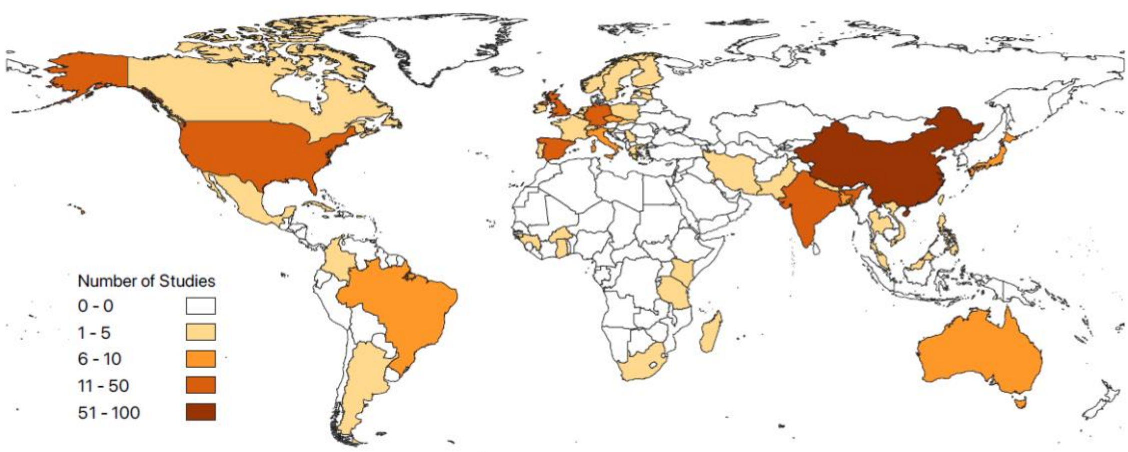

Figure 1: Country location of studies retrieved during first systematic review screening, when country or nationality was specified in article title e.g., “Italy”, “Italian”.

Preliminary findings

Spatial and sociodemographic heterogeneity in extreme temperature-related mortality

Global: Adverse temperature effects have been associated with negative health impacts on the population in many parts of the world. Epidemiological evidence consistently demonstrates that cold temperatures are attributed to a greater mortality risk than heat (Gasparrini et al., 2015). The effects of extreme cold can last up to 3 or 4 weeks, unlike heat, which is usually immediate and occurs within a few days (Analitis et al., 2008). An extensive body of epidemiological literature has documented that the effects of cold and heat-related mortality are generally unequal across axes of inequality such as age, sex, socioeconomic position, and geographic or climatic location (Analitis et al., 2008; Bakhtsiyarava et al., 2023; Marí-Dell'Olmo et al., 2019; Wan et al., 2022).

Age: The evidence on cold-related mortality is rather consistent with cold effects on mortality being the most pronounced among older people (Fu et al., 2018; Marí-Dell'Olmo et al., 2019). Older persons are more vulnerable to adverse temperature effects than younger age groups due to a reduced thermoregulatory capacity and diminished ability to perceive changes in their body temperature (Smolander, 2002). Masselot et al. (2023) found across 854 cities in Europe over the period 2000-2019, those aged 65, exhibited a cold and heat risk ratio (RR) of 1.21 (1.17, 1.26) from extreme cold and heat. In over-85s, cold-related RR was 1.36 (1.31, 1.40) and heat-related RR was 1.27 (1.23, 1.32).

Sex: For sex, the risks of mortality are more variable. Some studies in European regions have identified women to be at higher mortality risk from extreme cold(Donaldson et al., 2019; Keatinge et al., 1997), while other studies have showed no significant difference based on gender in South European countries (Marí-Dell'Olmo et al., 2019) and Japan (Onozuka & Hagihara, 2015); or have even observed men to be at higher risk in Spain (Achebak et al., 2019) and Scotland (Wan et al., 2022). For extreme heat, most studies identify women at higher mortality risk in the French summer heat wave in 2003 (Canoui-Poitrine et al., 2006), between 1990 and 2003 in elderly females in Galicia, Spain (DeCastro et al., 2011) and Belgrade, Serbia (Bogdanović et al., 2013). One study in Sweden found men to be more affected by heat than women, notably for those above 65 (Rocklöv et al., 2014).

Education: Generally, education level, income, and occupation are often used as an indicator of socioeconomic status (SES). Bakhtsiyarava *et al.,* (2023) reported that individuals and communities with lower SES were generally more vulnerable to the mortality effects of extreme heat temperatures. Greater cold-related mortality risks were found in individuals with no or low education (Marí-Dell'Olmo et al., 2019), and lower-level employment (Ingole et al., 2017). In communities with high levels of poverty, income inequality, and segregation, there was higher excess mortality (Bakhtsiyarava et al., 2023). Similarly, in subtropical regions, researchers emphasized that low individual SES groups and populations living in high density areas are more vulnerable to extreme heat (Liu et al., 2020). These findings suggest that lower SES groups are more vulnerable to cold-related mortality, which might be related to poor baseline health status, limited access to healthcare, and living conditions.

Geographic: Geographic and climatic locations play a pivotal role in determining the level of exposure to extreme temperature. Of all extreme heat excess deaths, 51.49% occurred in Asia, but Eastern Europe experienced the highest excess death rate, nearly five times the global average (Zhao et al., 2021). Moreover, studies reported that the effects of cold temperature are commonly larger in warmer climate regions and countries, at lower latitudes (Analitis et al., 2008), due to their generally weaker ability to adapt to cold conditions (Bao et al., 2016). Cold-related mortality was also found to have more risk in rural areas (Zhang et al., 2020), due to poorer access to health and heating infrastructure and generally hosting more vulnerable populations (e.g., older, and very young population), and economic conditions (Lal et al., 2011; Zhang et al., 2020). However, greater mortality risk can still occur in urban areas as well, as observed in Scotland (Wan et al., 2022).

Spatial and sociodemographic heterogeneity in natural hazard-related mortality

Global: More than 11,000 disasters triggered by natural hazards have been recorded since 1960 (Kharb et al., 2022). In recent years the rate of disaster occurrence has increased, namely floods and storms as has the average death rate, averaging 341 climate-related disasters annually between 2000 and 2013; up 44% from 1994-2000 average and over two-times that of between 1980 and 1989. Between 1994 and 2013 these disasters claimed over 1.35 million lives, an annual rate of approximately 68,000. Earthquakes (including tsunamis) were the largest killer between 1994 and 2013; drought has affected more than one billion people, despite accounting for only five percent of disaster events (CRED, 2015).

Age and sex: Children aged five and under experience the highest mortality risk globally from natural disasters, attributable to unsafe water and wasting from malnutrition in the aftermath of water related disasters (i.e., floods, storms, droughts) (Phung et al., 2016; Rodriquez-Llanes et al., 2016). Women are at greater risk, due to pervasive gender inequality, lack of access to education, social connections, and health services (Hamidazada et al., 2019). The United Nations Development Programme (UNDP) (2022) states women and children are 14-times more likely to die in a disaster. 70% of deaths in the 2004 tsunami were women (Okai, 2022). This inequality may be confounded by place of residence, rural areas observe higher mortality risk, and are often 'feminised' by the outmigration of men (Borden & Cutter, 2008; Gray et al., 2022).

Income/Education and Geographical: The mortality effect of natural disasters is disproportionally skewed toward poorer, isolated countries and communities (Gray et al., 2022; Lindersson et al., 2023), areas less likely to have infrastructure with the capacity to protect against disaster. Higher-income countries hosted 56% of disasters between 1994 and 2013 but lost 32% of lives, compared to lower-income countries experiencing 44% disasters and 68% deaths (Kharb et al., 2022). Standardised data from the CRED (2015) report suggests Mongolia; a strongly continental Koppen-Geiger climate and Eritrea; a subtropical desert climate zone experienced the worst mortality in the world, the heterogeneity in climate type supports the conclusion development and level of isolation are important predictors of mortality risk.

Discussion of preliminary findings

Sociodemographic heterogeneities helped explain the disparity in the population's experience with extreme temperature, with those in older age-groups (65+), low SES groups and unmarried people at greatest mortality risk from anomalies in ambient temperatures. Children and women were at greatest risk of mortality during natural hazards. Urban areas, acting as 'heat islands' also posed a mortality risk at higher temperatures. Rural areas were more exposed to cold risk, due to a lack of access to infrastructure. Effect of sex on temperature-related mortality varied by study, with most research identifying women of greater risk to both extreme heat and cold. Most research conducted was in high-income settings such as East Asia, Western Europe and North America and the field would benefit from greater study equity across world regions. We also recommend future studies include demographic and socioeconomic variables, to capture at-risk subgroups of populations to climate extremes.

Work in progress

A further screening will be conducted to limit the studies retrieved to those which quantitatively analyse the influence of the selected socioeconomic and geographical factors on climate-related mortality. A meta-analysis will then be performed, extracting effect estimates to produce models analysing the influence of these individual factors on climate-related mortality.

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