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

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1.Background: Motivation for research

The rising frequency and intensity of climatic extremes, such as heatwaves, droughts, floods, and storms, are increasing population exposure to extreme events worldwide [1-3]. These events include long-term shifts in precipitation, atmospheric circulation, and periods of extreme weather, as well as rapid-onset disasters like wildfires and floods. Historically, such events have heightened health risks and mortality. While higher-latitude wealthier nations may see health benefits from reduced extreme cold, tropical countries are likely to face a greater mortality burden due to extreme heat [4].

The intensity and unpredictability of weather patterns are expected to increase throughout the 21st century due to rising surface air temperatures. Global surface temperatures have risen by an average of 0.18°C per decade from 1973 to 2022 [5]. South Asia, particularly regions like western Afghanistan and southwestern Pakistan, has seen significant temperature increases, with annual rises of 1 to 3 degrees between 1950 and 2010 [6, 7]. The Arctic is warming even faster, with temperatures 3°C higher than pre-industrial levels. This warming leads to direct impacts like heat stress and water-borne diseases, and indirect effects such as crop failure and resource conflicts [6, 8].

The temperature-mortality curve typically follows a U or reverse-J shape, with elevated mortality at both temperature extremes. Cold exposure poses a greater mortality risk than heat, contributing to illnesses like pneumonia and exacerbating respiratory and cardiovascular conditions [9, 10]. Cold effects are prolonged, lasting up to 3-4 weeks, unlike heat impacts, which are more immediate [11]. While the physiological pathways for heat-related deaths remain unclear, heat increases cardiovascular risks [10]. Cold-related mortality is higher in tropical zones, while heat-related mortality peaks in central and eastern Europe [12]. These geographic variations underscore regional vulnerabilities, though methodological inconsistencies complicate demographic assessments of natural hazards' impacts.

Spatial and sociodemographic factors significantly influence climate extreme-related mortality, though evidence varies across studies and regions [6, 13, 14]. These inconsistencies complicate the development of risk mitigation policies aimed at vulnerable population subgroups. Thus, this study aims to conduct the first global systematic review of case studies, quantifying the relationship between climate extremes and mortality, while analysing the heterogeneous effects of spatial and sociodemographic factors. The review will summarize climate-related mortality associations across sub-populations stratified by age, sex, socioeconomic status, and geography, with the primary goal of identifying vulnerable populations and addressing knowledge gaps on a global scale.

2. Method: *search strategy and study selection*

A systematic literature review was performed, following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The protocol has been registered in the PROSPERO, an international prospective register of systematic reviews, with ID: CRD42024563147. Date restriction was applied in the search Web of Science (WoS) and Scopus. This was to identify observational studies investigating the relationship between extreme temperature, natural hazards, and mortality. The search for exposure cantered on extreme climate events: “climate change” OR “weather” OR “extreme temperature” OR “cold” OR “heat” OR “cold spell” OR “heat wave” OR “climate disaster” OR “flood” OR “storm” OR “hurricane” OR “tornado” OR “typhoon” OR “drought.” Outcome was focused on mortality: “mortality” OR “death” OR “all-cause mortality” OR “years of life lost (YLL)” OR “life expectancy”, in various permutations and combinations.

We selected quantitative observational studies that examined the general population and focused on mortality outcomes, including all-cause, non-accidental, natural mortality, and mortality from natural hazards. Eligible studies reported the direction or magnitude of the relationship between climate events (e.g., temperature, natural hazards) and mortality, and assessed the effects of spatial and sociodemographic heterogeneity on climate-related mortality. Studies on morbidity, air pollution, or future mortality projections were excluded. No restrictions were placed on exposure duration in the studies reviewed.

Initially, 3,376 articles from WoS and 7,942 from Scopus were combined, and duplicates were removed. Two investigators (SK and WK) screened the remaining articles, yielding 655 for full-text review. After reassessment, 370 articles met the inclusion criteria. An additional 5 records were identified through expert input, resulting in a final total of 211 articles for the systematic review.

3. Results

3.1 Temporal and geographical scope of reviewed studies

Out of 211 studies analysed, 187 (89%) focused on temperature-related mortality and 24 (11%) on natural hazards. Most studies (82%) were published since 2012. Temperature-related studies had study periods exceeding 5 years but less than 10 years, while natural hazard studies typically exceeded 20 years. The median year of the study period for most studies was 2000–2009, with 41% of temperature-related and 48% of natural hazard-related studies falling within this range.

Focusing on geographic distribution, the most temperature-related mortality studies were in Asia (90), Europe (48), and the Americas (30). China was the most frequently studied country with 63 studies, followed by the U.S. with 26 studies. Africa had the fewest studies. For natural hazard-related mortality, research was primarily in the Americas (12), with fewer studies in Asia (6) and Europe (3), and no studies in Africa, Oceania, or the Pacific. The U.S. was the most studied country in this category **(Fig. 1).**

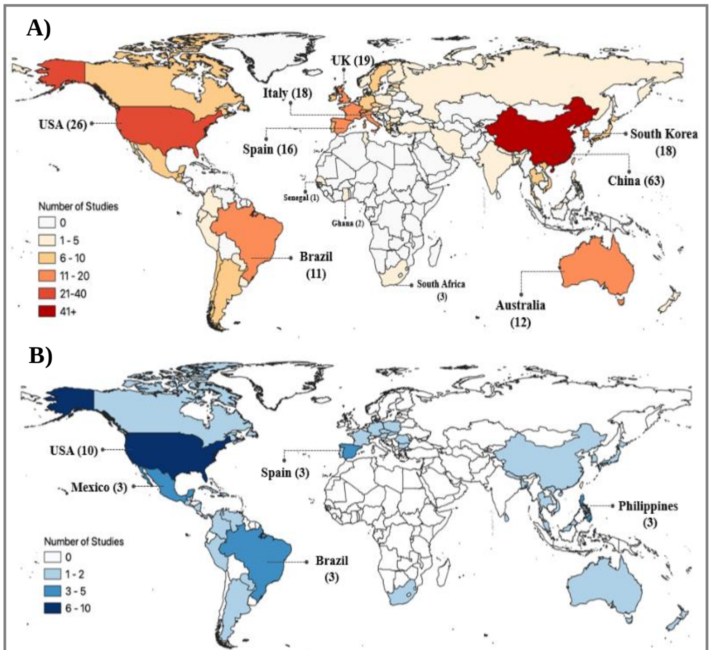

Fig. 1: *Panel A* shows geographic distribution of reviewed studies on temperature-related mortality: *Panel B* shows the distribution on natural hazard-related mortality (*N = 212;* an article can contain multiple case study locations)

3.2 Mortality measurement of reviewed studies

Of the 181 studies on temperature-related mortality, 180 used death counts, 7 used Years of Life Lost (YLL), and 3 used both metrics. For natural hazard-related mortality, 24 studies used death counts, and 1 used YLL. Most studies focused on daily mortality counts, with temperature-related studies often covering all age groups, while 11 studies examined specific age groups, primarily older adults.

3.3 Climate exposure of reviewed studies

Among the 211 studies, 89% (n=187) focused on temperature-related mortality. Of these, 104 studies (49%) examined both high and low temperatures or heat waves and cold spells, 70 studies (33%) focused solely on high temperatures or heat waves, and 13 studies (6%) on low temperatures or cold spells. Daily mean temperature was used in 104 studies (56%). Other metrics included multiple temperatures, maximum temperature, and diurnal temperature range. There are 24 studies (11%) investigated mortality related to natural hazards, with a focus on flooding (n=7), drought (n=5), and tropical storms (n=12), which include hurricanes, tornadoes, and typhoons.

3.4 Summary of vulnerability assessment for climate-related mortality

Fig. 2 summarizes the evidence for effect modification in *the temperature-mortality relationship* by individual and geographic characteristics. Risk estimates for heat were generally higher for female, with 58 studies showing greater effects for females compared to 16 studies for males. For cold exposure, strong evidence indicates higher risks for female. Additionally, 110 studies reported increased heat-related mortality risk among older people, while 49 studies observed higher risks from cold exposure in this age group. Twenty-two studies reported higher heat-related mortality risks among individuals with lower or no education compared to those with higher education, while 12 studies noted similar trends for cold-related mortality. Nine studies found no educational differences in mortality risk—four for heat and five for cold. Limited evidence suggests increased temperature-mortality risks associated with low socioeconomic status (SES) for both heat and cold, with urban areas showing higher risks for heat and rural areas for cold. Strong evidence indicates that Asia faces a higher risk from cold than heat (37 studies), whereas Europe shows limited evidence of higher risk from heat than cold (12 studies).

When focusing on *natural hazards-related mortality*, limited or suggestive evidence indicates that males may face higher mortality risk during tropical storms (5 studies), while females may be at greater risk during droughts (2 studies). Additionally, limited evidence suggests that older individuals may have higher mortality risks during tropical storms (7 studies) and droughts (3 studies). However, this review found weak evidence for increased mortality risk associated with low SES during tropical storms and floods, and with rural areas during tropical storms **(Fig. 3)**.

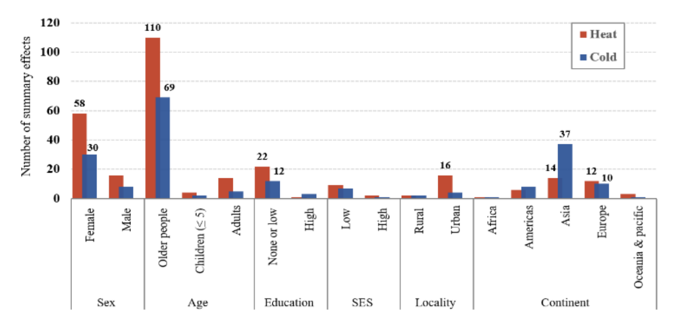

Fig. 2: Summary of vulnerability assessment for temperature-related mortality

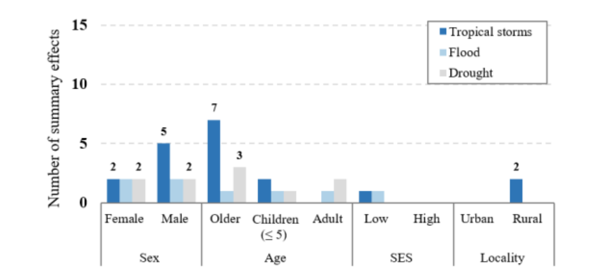

Fig. 3: Summary of vulnerability assessment for natural hazard-related mortality

4. Discussion

In this systematic review, we assessed studies examining the association between climate events (e.g., temperature extremes, natural hazards) and mortality, with a focus on identifying factors influencing vulnerability. Our findings indicate that exposure to heat, cold, extreme temperature events, and natural hazards such as flooding, drought, and tropical storms generally increases mortality risk. We identified evidence of effect modification related to several individual-level factors, including sex and age, which influence vulnerability to climate-related mortality.

4.1 Effect modifiers of extreme climate -related mortality

Sex: We found strong evidence of higher mortality risks associated with both heat and cold exposure for females compared to males. Several studies have identified females as being at greater risk of mortality during extreme high temperatures such as in China [15-17], India [18], Italy [19], and Ghana [20]. Additionally, studies in European regions have consistently reported higher mortality risks from extreme cold among females [21-23]. This may result from differences in physiology, exposure patterns, and occupational exposure between males and females [24, 25]. However, some studies reported no difference in risk between male and females [26], or a higher estimated effect for males [27]. For the natural hazards investigated, limited evidence on sex heterogeneity was found, with similar number of studies which found significant evidence on females and males or null association. Specifically, by the type of natural hazards, our analysis indicated that males seem to be at higher risk during tropical storms [28-30], while females may face a higher risk during droughts [31].

Age: We observed age to be the most consistent factor in defining the relationship between extreme temperature and mortality, facing greater risks from both heat and cold exposure. Overall, our review determines that older adults had the highest relative risk (RR) [32, 33], the largest YLL [34], excess deaths (ED) [35], and percentage change in mortality [36] under both extreme cold and heat. Older persons are more likely to have co-morbidities that increase the risk of mortality in periods of extreme temperature, this includes diminished capacity in sweat glands, blood circulation or compromised immune systems [37]. Furthermore, older people may live situations of loneliness [38, 39], have lower level of income [40], or not have available some important mitigation aspects such as the presence or absence of air conditioning and heating. Regarding natural hazards, the available evidence suggests that older individuals and children are at higher risk during tropical storms [28] and droughts [31]. While, floods have been shown to disproportionately affect adults, indicating their vulnerability in such events [41].

Education level/SES: Generally, education level is often used as an indicator of SES, and many studies reported greater extreme temperature-related mortality risks were found in individuals with no or low education [42-44], and lowest across highly educated groups. Moreover, both cold and heat effects-associated YLL were higher in persons with low education than those with higher education level [45]. However, some studies also identified no difference [46] or higher risk for those with higher education level [39, 47]. Similarly, lower SES has been consistently associated with increased vulnerability to extreme temperatures, particularly during heatwaves. Those living in low-SES regions are at greater risk of heat-related mortality, especially in subtropical areas where populations in densely populated and economically disadvantaged areas face higher exposure [48, 49]. These findings suggest that lower educated and less SES groups are more vulnerable to extreme temperature-related mortality. This increased risk is likely due to factors such as poor baseline health, limited access to healthcare, inadequate housing, and a lack of preventive knowledge and less resilient in coping strategies when faced with extreme heat or cold. Regarding natural hazards, weak evidence suggests that low SES may act as an effect modifier during tropical storms [50] and floods [51], while there is also limited evidence indicating that high educational attainment could serve as an effect modifier during floods[52].

Rural/Urban*:* Findings suggest that a greater mortality risk for heat in urban areas due to "heat island" effects [48, 53, 54]. Cold-related mortality was generally found to pose a higher risk in rural areas [55] 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 [56]. Regarding natural hazards, there is limited evidence suggesting an association between rural areas and increased vulnerability during tropical storms [30, 57].

Continent: The majority studies investigated in this review are located in Asia and Europe. Findings suggest that the effects of cold temperature on mortality are commonly larger in warmer climate regions and countries, at lower latitudes, due to their generally weaker ability to adapt to cold conditions [11] .

5. Conclusion

This review analyzed 211 studies across all continents, revealing significant sociodemographic and geographic variations in climate-related mortality. Female face higher risks during both heat and cold exposure. Vulnerability increases with age and pre-existing conditions. Urban areas experience heightened heat-related mortality due to "heat island" effects, while rural areas are more vulnerable to extreme cold. In high-latitude regions, cold poses the greatest risk, while tropical regions, such as southern Asia and Africa, face greater heat-related mortality and a dual burden from temperature extremes. However, there remains a shortage of studies from Africa. The review found few studies on natural hazard-related mortality, highlighting the need for more research on deaths caused by events like floods and storms. Future analysis will focus on meta-analyses to better quantify the impact of sociodemographic and spatial factors on climate-related mortality.

6. Reference

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