

Degrees of Inequality: How educational attainment shapes mortality associated with non-optimal temperatures in Belgian provinces

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Background

Climate change represents one of the most pressing health challenges of our time. By 2070, up to 3 billion people could be exposed to climatic conditions unlike any experienced in the past 6,000 years (Xu et al., 2016). Current greenhouse gas emissions are not on track to meet Paris Agreement targets, instead aligning with intermediate to high-emission scenarios that suggest considerable warming over the coming decades (Calvin et al., 2023).

While the health impacts of temperature extremes are well-documented, much less is known about how these impacts vary across socioeconomic groups. In Belgium, where individual mortality data by educational attainment is available, heat-related mortality is expected to rise due to both climatic and demographic changes (Crouzier et al., 2024), yet its differential impact across socioeconomic groups remains insufficiently studied (Demoury et al., 2022).

This study addresses a critical gap by examining how educational attainment—a key indicator of socioeconomic status—shapes vulnerability to temperature-related mortality among the elderly population across Belgian provinces. We used mortality data from 2000-2019 covering 1,373,682 deaths among individuals aged 65 and above to investigate temperature-mortality relationships across different educational groups and geographic regions.

Theoretical framework

Temperature-mortality relationships typically show U-shaped patterns where mortality risk increases at both cold and hot temperature extremes (Gosling et al., 2009). Globally, over 5 million deaths annually are associated with non-optimal temperatures, with cold-related deaths comprising 8.52% while heat-related deaths account for 0.91% of total mortality (Zhao et al., 2021).

While temperature affects all populations, individual

characteristics significantly modify these relationships. Educational attainment emerges as a particularly important modifier because it captures knowledge and cultural capital that determine healthcare access (Eggerickx et al., 2020). Education enhances cognitive development and decision-making capabilities relevant for climate adaptation, while also reducing vulnerability through improved socioeconomic status and social capital (Lutz et al., 2017). Empirical evidence shows adults with 12 years of schooling have 24.5% lower mortality risk compared to those with no schooling (Balaj et al., 2024).

However, research on temperature-specific educational gradients reveals complex patterns that vary by context (Marí-Dell’Olmo et al., 2019). The overall evidence base remains limited, with systematic reviews providing only suggestive evidence of higher risk associated with low educational attainment for both heat and cold exposure (Son et al., 2019).

Belgium provides an ideal context for examining these educational gradients due to its documented geographic health disparities. The north-south health divide shows morbidity and mortality generally higher in southern regions, with clear geographic patterns for cardiovascular disease, diabetes, and other conditions (Van Hemelrijck et al., 2016).

Furthermore, analysis of young adult mortality demonstrates that educational expansion partially explains mortality decline, as higher educated individuals maintain mortality rates two to three times lower than those with lower educational attainment (De Grande et al., 2014). However, the extent to which educational expansion influences mortality trends varies by urbanization level, indicating that contextual factors modify educational effects on health outcomes.

These Belgian patterns underscore the necessity of examining both individual educational attainment and spatial context when analyzing temperature-related mortality disparities, making Belgium an ideal setting for comprehensive

analysis of educational gradients in temperature-related mortality.

Data and methods

We analyzed Belgian mortality data from 2000-2019 obtained from death registries, covering 1,372,682 deaths among individuals aged 65 and over across the 11 Belgian provinces. Deaths were classified by three educational levels: low (none/primary), secondary, and superior education. Daily temperature data were obtained from the Belgian Royal Meteorological Institute. Future analyses will incorporate data from 2020 onwards to extend the observation period and improve the precision of our estimates.

We applied the two-stage meta-regression framework developed by Masselot et al. (2025), which was specifically designed for multi-location temperature-mortality studies. In the first stage, we estimated location-specific temperature-mortality associations using distributed lag non-linear models (DLNM) with quasi-Poisson regression. The second stage pooled province-specific estimates while accounting for regional meta-predictors including socioeconomic indicators (GDP per inhabitant, employment rates, population density), environmental factors (imperviousness, tree cover, water coverage), and demographic characteristics (population over 65, baseline mortality rates).

Two main models were fitted: (1) age-stratified analysis across three groups (65-74, 75-84, 85+ years), and (2) education-stratified analysis across educational categories. We identified minimum mortality temperatures (MMT) and calculated relative risks at temperature extremes.

Key findings

Age-related patterns

Strong age gradients are evident in the temperature-mortality relationships (Figure 1). The 65-74 age group shows moderate temperature sensitivity with RRs remaining below 1.5 at the 1st percentile. The 75-84 age group demonstrates increased vulnerability, particularly to heat exposure where RRs approach 2 at the 99th percentile. The 85 and over age group shows the highest vulnerability to both extremes, with RRs exceeding 2.5 at the highest temperatures.

Cold-related mortality dominates across all age groups. Standardized excess death rates progress from around 100 per 100,000 for ages 65-74 to over 1,250 per 100,000 for ages 85+, representing a 12-fold increase. Heat-related mortality shows lower absolute rates, ranging from near-zero for the youngest elderly to approximately 100 per 100,000 for the oldest group.

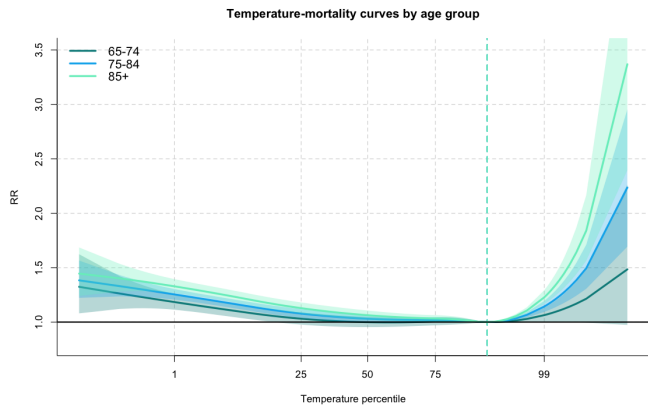


Figure 1: Temperature-mortality relationships by age group. Clear age gradients are evident, with the oldest group (85+) showing the highest vulnerability to both cold and heat extremes.

Educational attainment patterns

Educational differences in temperature-mortality relationships are evident but uncertain (Figure 2). The low education group shows modest cold effects with RRs below 1.4 at the 1st percentile, but the highest heat effects with RRs reaching 2.5. The secondary education group demonstrates intermediate patterns with RRs reaching 1.3 for cold and 1.9 for heat. The higher education group shows high uncertainty but appears to have elevated cold vulnerability with RRs reaching 1.8 at the first percentile.

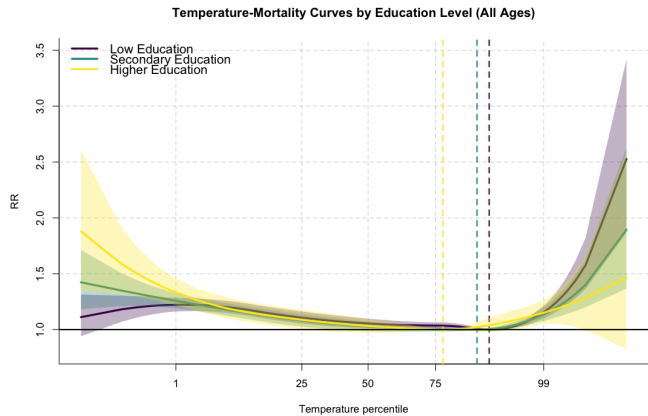


Figure 2: Temperature-mortality relationships by educational attainment. All education groups show U-shaped curves, but with different minimum mortality temperatures and risk magnitudes at temperature extremes.

When looking at aggregated results for all the provinces, no clear educational gradient can be defined given large confidence intervals. Cold-related mortality dominates across all educational groups, with standardized excess death rates ranging from approximately 450 per 100,000 for low education to around 250 per 100,000 for higher

education.

Geographic patterns

Significant regional variation reflects established north-south health disparities (Figures 3 & 4). Southern provinces (Walloon region) show higher excess mortality rates than northern provinces (Flanders) across both age groups and educational categories.

The age-stratified map (Figure 3) reveals clear gradients within each province, with consistently higher excess mortality rates in older age groups across all regions. The spatial pattern shows a north-south divide, with southern provinces displaying darker shades indicating higher excess mortality, particularly pronounced in the oldest age group.

The education-stratified map (Figure 4) demonstrates that educational gradients exist within each province, with the lowest educational attainment group consistently showing the highest excess mortality rates (darkest shades) across all regions. This pattern is particularly evident in southern provinces where the gradient between educational groups is most pronounced.

Provinces with highest excess mortality include Hainaut (285 per 100,000), Namur (267 per 100,000), and Liège (241 per 100,000), while lowest rates occur in West Flanders (156 per 100,000) and Antwerp (168 per 100,000). These geographic disparities persist across both age and educational stratifications, indicating that regional factors compound individual-level vulnerabilities.

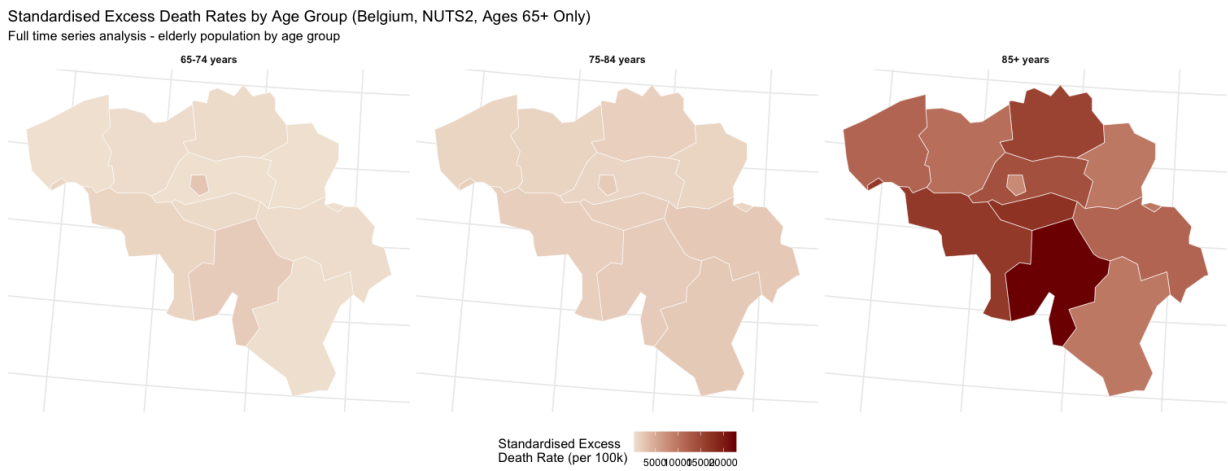


Figure 3: Geographic distribution of standardized excess death rates by age group across Belgian provinces. Southern provinces consistently show higher rates across all age groups, with the most pronounced differences observed in the oldest age group.

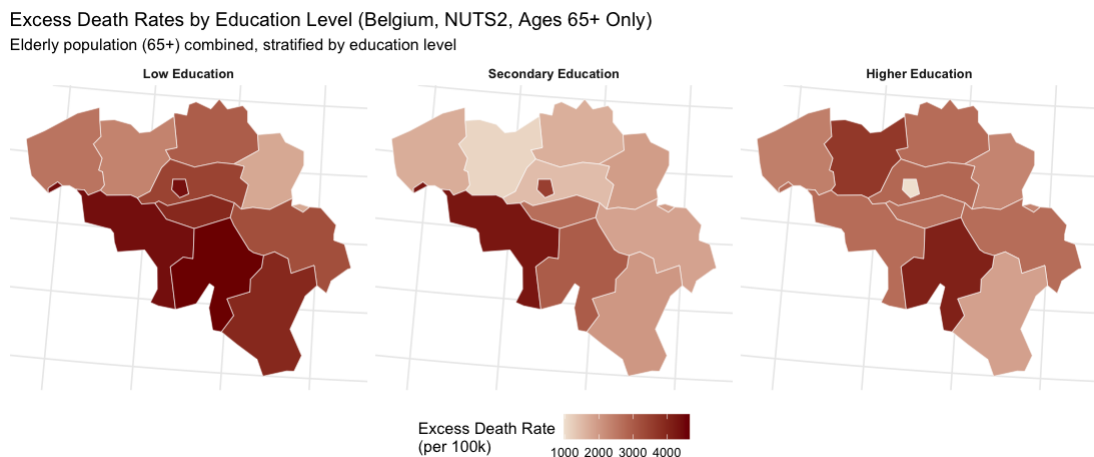


Figure 4: Geographic distribution of standardized excess death rates by educational attainment across Belgian provinces. Educational gradients are evident within each province, with low education groups consistently showing higher excess mortality rates, particularly in southern provinces.

Future research

For the conference presentation, we will extend the analysis to NUTS 3 level using more detailed metadata to provide finer geographic resolution. Additional environmental and socioeconomic predictors will be incorporated, including healthcare infrastructure indicators and deprivation indices.

Conclusions

This study provides robust evidence for age-related gradients in temperature-mortality vulnerability among Belgian

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- elderly populations, with the oldest groups (85+) facing substantially higher risks at both temperature extremes. Educational disparities in temperature vulnerability exist but with larger levels of uncertainty. Results encourage further analysis at a smaller geographic scale.
- The educational gradients observed highlight the importance of addressing social determinants of health as part of climate adaptation strategies. As climate change intensifies, understanding these intersection patterns becomes critical for developing equitable adaptation strategies that protect the most vulnerable populations.
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