Regional Differences in Temperature-Related Mortality Burden in Russia

1. Introduction:

Non-optimal temperatures are consistently linked to increased mortality risks (Son et al., 2019), with relationships typically following J-, U-, or V-curves (Gasparrini et al., 2015). However, different temperature ranged present varying temporal effects: heat-related mortality occurs rapidly (within days), while cold effects persist longer (up to one month) (Bao et al., 2016). Temperature-related mortality demonstrates clear age- and cause-specific patterns: most deaths occur among vulnerable groups, including older adults and those with chronic conditions due to exacerbation of circulatory and respiratory illnesses (Seltenrich, 2015)

Despite generally higher heat-related mortality risks, most deaths remain attributable to non-extreme cold due to more frequent exposure (Gasparrini et al., 2015, Alahmad et al., 2025), although projections suggest increasing heat burden (Vicedo-Cabrera et al., 2018). In cold-climate regions, however, warming may reduce temperature-attributable mortality via decreased cold exposure (Revich et al., 2020)."

In this context, Russia presents a unique case due to prolonged extreme cold exposure potentially leading to population adaptation and reduced cold-related mortality (Donaldson et al., 1998a), but limited experience of rising extreme heat events (Meehl & Tebaldi, 2004). Pronounced regional mortality disparities, including center-peripheral divides (Shchur & Timonin, 2020; Shchur et al., 2021) and northeast-southwest gradients, may further interact with climatic heterogeneity to modify temperature-mortality relationships.

Early studies reported modest cold-related mortality in Russia (Donaldson et al., 1998a, 1998b). Subsequent research found northern cities face elevated extreme cold risks (Revich et al., 2019; Revich & Shaposhnikov, 2022), while southern cities experience greater heatwave mortality (Revich et al., 2015; Revich & Shaposhnikov, 2016). Following unprecedented 2010 heatwave numerous impact assessments were conducted at city (Shaposhnikov et al., 2014) and regional levels (Revich, 2011).

Comprehensive nationwide research emerged only recently: Timonin et al. (2025) analyzed over 300 cities, revealing cold-related mortality predominance, especially in Siberia. However, peripheral areas and smaller settlements remain understudied. This study addresses this gap by providing regional-level temperature-mortality estimates across all Russian regions, allowing for comprehensive assessment of geographic and climatic modifiers of this phenomenon.

2. Data and Methods:

This study analyzed 80 Russian federal subjects from 2004 to 2019, a period of sustained life expectancy increases (Shkolnikov et al., 2013) preceding the COVID-19 pandemic. Weekly age-standardized death rates (ASDRs) were obtained from the Russian Short-Term Mortality Fluctuations (RuSTMF) dataset based on official statistics. Temperature and air pollution exposure data were provided by ECMWF's EAC4 reanalysis (Inness et al., 2019) via the Copernicus Atmosphere Data Store, with 0.75° × 0.75° spatial resolution. Weekly estimates were derived by averaging 3-hourly data. PM2.5 and ground-level ozone (converted to kg/m³) included as confounders. Region-level exposures were calculated as population-weighted averages using Gridded Population of the World v4 (GPWv4) data at 0.5° × 0.5° resolution. Socioeconomic covariates included gross regional product (GRP) per capita (inflation- and price adjusted), and educational attainment (interpolated from 2002, 2010, and 2020 censuses).

This study employed a standard two-stage analytical framework (Gasparrini et al., 2012). First, region-specific quasi-Poisson time-series regression were fitted using distributed lag models (DLMs) to examine temperature-mortality associations (Gasparrini et al., 2010). Second, region-specific estimates were pooled in meta-regression with geographic and socioeconomic meta-predictors to produce national-level exposure-response curves. Best Linear Unbiased Prediction (BLUP) was then applied to refine region-specific estimates, which were used to calculate attributable fractions (AFs) quantifying temperature-related mortality burden."

In the first stage, weekly ASDR were modelled using quasi-Poisson regression by a crossbasis function using natural cubic splines with knots at the 10th, 75th, and 90th percentiles for exposure-response relationship, and three integer weekly lags. Models controlled for temporal trends and seasonality (natural cubic spline, 8 df per year), adjusted for PM2.5 and O3 confounding, and included logarithm of annual average population as an offset. Model specification is as follows:

$$\log\left(E\left(Y_i\right)\right)=intercept+cb\text{¿}$$

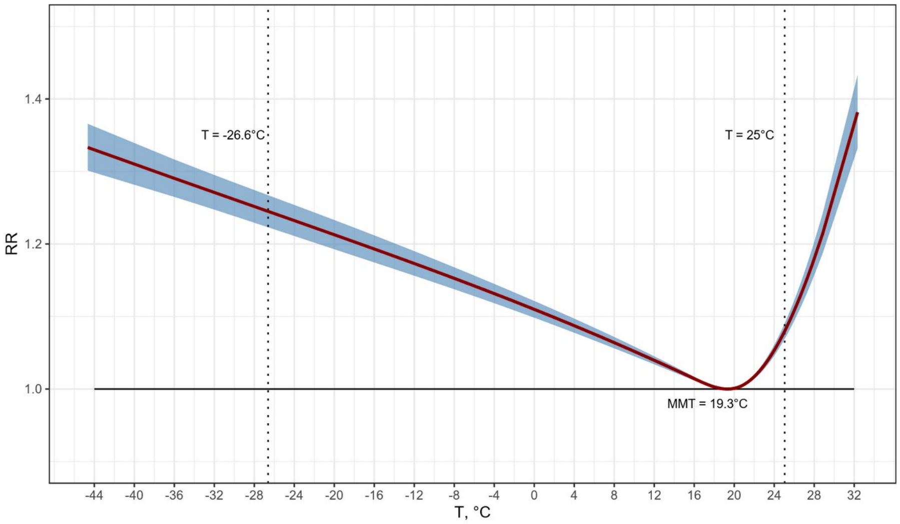
In the second-stage, region-specific coefficients were pooled via multivariate meta-regression with regional random effects. Meta-predictors included log-transformed GRP per capita, proportion of individuals older that 15 with education level lower than-secondary, and mean summer/winter temperatures. Selection of meta-predictors was guided by minimization of between-region heterogeneity (estimated using I² statistics).

BLUP-derived regional temperature-mortality curves were centered on region-specific minimum mortality temperatures (MMTs), defined as temperatures with minimum relative risk. AFs were calculated on their basis via forward perspective (Gasparrini & Leone, 2014), categorizing exposures into cold (below MMT) and heat (above MMT). 95% confidence intervals (CI) were calculated for AF and MMT using 500 Monte Carlo simulations (Vicedo-Cabrera et al., 2021). Results were mapped using QGIS 3.40.

3. Results

The pooled analysis revealed a J-shaped exposure-response relationship between temperature and mortality in Russia, with minimum mortality temperature (MMT) at 19.3°C (89.5th percentile of the national temperature distribution). Extreme cold exposure at the 1st percentile (−26.6°C) was associated with substantially higher mortality risk (RR = 1.30, 95% CI: 1.26–1.34) than extreme heat at the 99th percentile (25.0°C; RR = 1.09, 95% CI: 1.06–1.11) (Fig. 1).

Figure 1. Temperature-Mortality Exposure-Response Relationship in Russia, 2004-2019



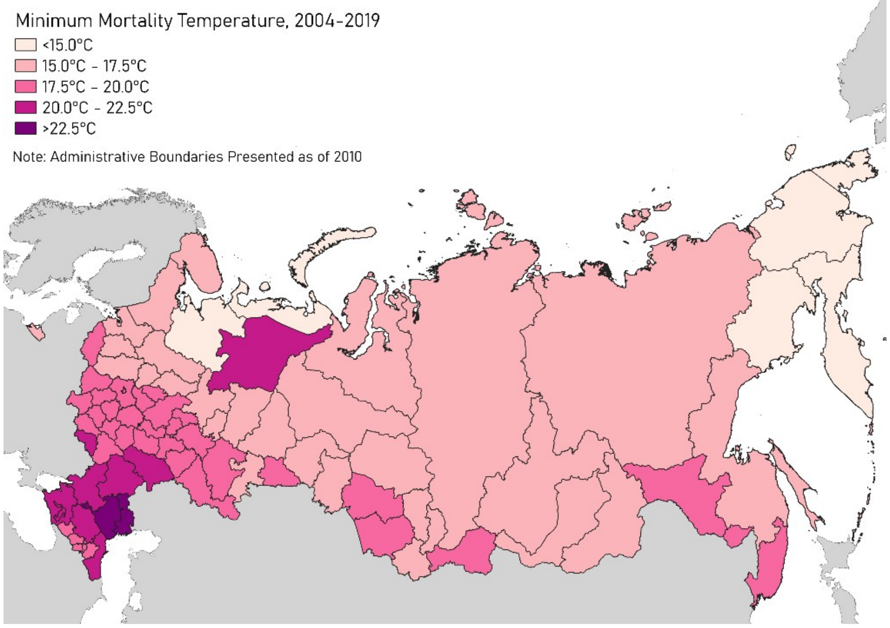
BLUP-estimated regional exposure-response curves presented similar J-shaped patterns with predominant cold-related risks. Exceptions included Volgograd Oblast, where heat extremes (RR = 1.60) exceeded cold extremes (RR = 1.39). Many cooler regions, particularly in subarctic areas such as Murmansk Oblast and Kamchatka Krai, showed no significant heat effects (95% CI included unity).

Regional distribution of MMT revealed a clear north-south gradient, ranging from 12.6°C (95% CI: 9.3–12.6°C) in northeastern Magadan Oblast to 23.5°C (95% CI: 23.1–23.9°C) in southern Kalmykia, reflecting climatic adaptation patterns (Fig. 2). Minimum mortality percentiles (MMPs), the temperature percentile corresponding to MMT, showed an inverse spatial pattern.

Cold-related AFs presented substantial spatial heterogeneity. Lowest values occurred in North-West (8.31%, 95% CI: 6.03–10.39%) and North Caucasus microregion located in southern European Russia (8.85%, 95% CI: 6.23–11.22%). Highest AFs were observed in Arctic Chukotka Autonomous Okrug (25.57%, 95% CI: 9.45–38.66%), the Far East (12.22%, 95% CI: 7.98–15.96%), and the Volga economic macroregions (11.9%, 95% CI: 10.32–13.49%).

Heat-related AFs were minimal or absent in colder regions (e.g., 0.23%, 95% CI: −0.06–0.50% in North-West) but elevated in southern European Russia, where heatwaves are more frequent, namely Central Black Earth (1.23%, 95% CI: 0.97–1.49%) and North Caucasus (1.31%, 95% CI: 0.84–1.74%) macroregions.

Figure 2. Minimum Mortality Temperatures in Regions of Russia, 2004-2019



4. Discussion

This nationwide regional-level analysis confirms prior findings from city-level studies in Russia: cold-related mortality predominates in northern territories with negligible heat exposure (Chernykh & Taseiko, 2018; Revich et al., 2019; Shaposhnikov et al., 2019; Shartova et al., 2019), while southern regions face elevated heatwave risks (Revich et al., 2015; Revich & Shaposhnikov, 2016). Outcomes of this study parallel Timonin et al. (2025) in geographical patterns and numerical estimates but extend spatial coverage to remote rural and peripheral areas rarely considered previously. Notably, Arctic regions present monotonic risk decline due to absent heat exposure, a distinctive pattern rarely emphasized elsewhere.

Observed spatial AF patterns primarily represent climatic differences: Northwestern Russia shows lower cold-related mortality due to the predominance of maritime air masses leading to mild winters, while Volga macroregion present unexpectedly high mortality even at modest cold exposure (>−10°C), suggesting worse preparedness to cold exposure. In Arctic and extremely continental regions, most cold-related AFs are attributable to extreme cold (<−20°C) due to both prolonged exposure and elevated risks at these temperatures. Conversely, heat-related mortality evidence remains limited, with many regions experiencing it only during distinct events (e.g., the 2010 heatwave), contrasting with annually experienced cold-related mortality.

Russian MMTs ranged from 14°C in subarctic regions to 21°C in southern areas (80th-90th percentiles), comparable to 17°C (77th-95th percentiles) in Northern Europe (Tobías et al., 2021), with northward decline reflecting greater cold adaptation among populations accustomed to low temperatures (Yin et al., 2019). Cold-related AFs in Russian regions (8–15%) exceed global averages but align with Northern and Eastern Europe (9.76%) (Masselot et al., 2023), reflecting elevated cold exposure. While heat-related AFs in southern Russia (1–2%) correspond to Southern Europe (1.15%), northern regions show minimal heat mortality like Northern Europe (0.22%) (Masselot et al., 2023; Vicedo-Cabrera et al., 2021).

Several limitations should be noted. Relatively coarse resolution (0.75° × 0.75°) of exposure data may inadequately capture localized phenomena such as urban heat islands, reducing representativeness of estimates. Weekly temporal aggregation, while methodologically appropriate (Ballester et al., 2024), may smooth short-term temperature spikes and underestimate acute heat-related mortality. Large regional sizes, especially in Asian Russia, result in excessive spatial averaging that overlooks important local variations. Despite these limitations, this study provides the comprehensive regional-level assessment of temperature-mortality relationships across all Russian federal subjects, highlighting spatial heterogeneity in temperature impacts and revealing novel regional profiles of temperature-related mortality.

5. Conclusions

This study identified geographic patterns in temperature-related mortality burden across entire territory of Russia. A clear north-south gradient in minimum mortality temperatures and percentiles was confirmed, suggesting greater adaptation to heat in southern Russia.

Consistent with previous research, cold-related risks predominate across Russia, with attributable fractions in many regions exceeding global averages but similar on average to those observed in Northern and Eastern Europe. In contrast, heat-related mortality, although present, is primarily concentrated in areas with substantial heat exposure. Overall, AF values are generally comparable to those observed in countries with comparable climatic conditions.

Notably, many regions showed an atypical exposure-response curve, characterized by a monotonically decreasing temperature-related mortality risk with rising temperatures. This pattern explains the absence of a measurable heat-related mortality burden in these areas. Identified geographic variations imply that geographic latitude and climatic continentality influence temperature-related mortality. These findings highlight the need for further analysis incorporating additional geographic and socioeconomic determinants.

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