**Excess Mortality in Cities and Regions of European Russia During 2010 Heatwave**

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**Introduction**

Due to long-term climate changes extreme weather events frequency and severity has been increased substantially in recent years (Ridder et al. 2022). This not only contributed to a significant increase in mortality and morbidity but also exacerbated inequality in health trends as various groups were affected by heatwaves disproportionately. In spite of being extensively studied in the developed countries, the consequences of notorious summer 2010 heatwave in Russia are still obscure. This study is intended to estimate the effects of such event on mortality increase in European Russia and to explore its spatial patterns.

Heat-related excess mortality attracted the attention of scholars after a series of events such as 1995 Chicago heatwave and the heatwave of 2003 in Europe. In most studies similar conclusion on age composition and main causes of excess mortality were drawn. Elderly people are much more vulnerable during heatwaves, while cardiovascular and respiratory diseases contribute the most to the mortality increase (Kovats and Hajat, 2008). However, a number of findings in various researches remain controversial. For instance, spatial patterns investigated in numerous researches provide conflicting views on north-south divide in heat-related effects (Basu, 2009; Grigorieva and Revich 2021). The difference between urban and rural areas were rarely mentioned as well because most of the studies are devoted to large cities contributing the most to overall death toll. On the one hand, due to “urban heat island” effect urban dwellers are exposed to a larger risk attributed to extreme temperatures (Buechley et. al., 1972). On the other, economic deprivation is associated with greater mortality increase during extreme weather events so economically backward rural territories might experience other risk factors (Rey et al. 2009).

There are two major approaches in the assessment of the extreme temperature impact on human health on mortality: episode analysis and continuous-temperature time-series analyses (Gasparrini and Armstrong 2011). The first approach is based on comparing the observed values with the reference (expected non-heatwave) figures (Semenza et al. 1996, Robine et al. 2007). This allows to estimate an overall death toll and burden of heat waves. Another approach considers modelling mortality with the inclusion of certain risk factors (exposure-response relationship). The most commonly used parameters in such models are temperature and air quality indicators and thermal indices (Shartova et al. 2018). This approach is used to calculate the impact of various factors on mortality and morbidity increase.

**Data and methods**

In this study excess mortality is estimated for 54 regions (for urban and rural population distinctively) and 126 big cities (100,000+ inhabitants) of European Russia. Age and sex structure was provided by Russian Fertility and Mortality Database (<http://demogr.nes.ru/index.php/en/demogr_indicat/data>) and Rosstat for population of regions and cities respectively. Individual death records were obtained from Rosstat and aggregated by 5-year age groups and ISO-weeks.

Excess mortality was estimated for 05.07 – 22.08 (27-33 ISO-weeks of 2010) the period of overall temperature increase. Heatwave has affected the territory of European Russia both in space and time so the broad period of study was deliberately selected. Excess mortality was considered as the difference between observed (O) and expected (E) figures evaluated by the baseline model. It was calculated for both total number of deaths and ASDRs.

The key issue was the baseline model selection. Various studies use average and trend estimations for the reference period, spline and Fourier series with different hyperparameters (Gasparrini and Armstrong, 2011). According to AIC minimization an optimal model was selected among over 50 formulas. Final regression included yearly linear trend, weekly B-spline with 7 knots and 3 degrees of freedom, two pairs of trigonometric functions. 95% confidence intervals were also calculated for all the week expected mortality estimates via bootstrap. All the data analysis, model selection and calculation were performed in R 3.6.2.

**Results**

Total amount of excess deaths during 2010 summer heatwave was estimated at 57,700 (95% CI: 41,700 – 72,400). A half of them was concentrated in 7 regions; City of Moscow, Moscow, Nizhny Novgorod, Samara, Saratov, Rostov oblasts and Tatarstan. Rural areas comprising 26,8% of European Russia population, accounted for 18,1% excess deaths. Middle Volga and Central Black Earth regions have experienced much more profound mortality increase as well as Moscow. According to LISA high mortality cluster was identified stretching from Voronezh and Kursk oblasts to Chuvashia and Mari El republics. In contrast, in Northeastern and North Caucasus regions excess mortality was not observed.

**Discussion**

In general, excess mortality rates in terms of ASDR were higher in cities with over 500,000 inhabitants. However, results of baseline estimation were inconsistent for many cities with fewer than 200,000 inhabitants due to small number of observed deaths and wide confidence intervals.

Regions with the lower expected mortality rates have experienced greater mortality increase during the heatwave. This could be explained by limitations of the selected baseline model or by “low base effect”. In regions with recent rapid mortality relative increase in death rates was much more significant for both urban and rural population. However, strong correlation was not revealed for big cities of European Russia.

Area of the greatest mortality excess coincided with the zone of blocking high extent, causing the heatwave with the highest temperature extremes. Duration of heatwave also strongly correlated with the excess mortality. However, the impact of forest and peat fires and air pollution also responsible for cardiorespiratory mortality increase (Analitis et al. 2012) was not studied in this work in depth.

While the temperature records on most affected territories were broken during 30-32 weeks, the majority of excess deaths occurred at the same period. In large cities weekly mortality fluctuations were severe which could be explained by “urban heat island” effects. However, no lags were identified in the scope of weeks. Compensatory fall of mortality after the heatwave occurred in several cities, although harvesting effect was not consistent as well.

The impact of certain risk factors on relative mortality increase in big cities was studied by logistic regression analysis. A list of risk factors was included in regression models:

* Heatwave duration: total and consecutive number of days with average temperatures exceeding 97th percentile
* Temperature: PET (Physiological Equivalent Temperature) and mean 2-meter temperature deviation
* Social and economic development: the share of people with higher education; city population size, age composition (share of older people), expected mortality rate as proxy parameters

Among 15 regression models with various parameters included the best regression models contained 2-meter temperature deviation, total number of heatwave days, the expected mortality rate and population category by size as independent variables. According to the results of regression analysis, heatwave severity contributed the most to mortality increase, whereas the selected proxy social and economic variables were much less significant. Although other factors might provide greater explanatory power.

**Conclusion**

The consequences of long-term climate change were of major concern to scientist. The aim of the study was to assess excess mortality during 2010 heat wave in European Russia A number of issues on excess mortality patterns and determinants has been investigated in this work. The following conclusions are worth mentioning:

* Largest cities (500,000+) had experienced greater mortality increase possibly due to more pronounced “urban heat island” effects and lower baseline level. However, certain risk factors were not defined and assessed
* Black Earth and Middle Volga regions hardest hit by heat wave concentrated most excess death, while Northeast and North Caucasus remained almost unaffected
* Lag effects and mortality displacement were not identified in the scope of weeks. Mortality extremes in general coincided with temperature records, although the impact of air pollution and wildfires might be significant as well

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