Spatial Patterns of Excess Mortality during 2010 Heatwave in European Russia

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Climate change and public health

- **Global climate change** increases **frequency** and **severity** of **extreme weather events**: heatwaves, droughts, forest fires, etc.
- Among them **heatwaves** have especially strong negative impact on public health because of the **heat stress** and **worsened air quality**
- Most studies draw similar conclusions on age and cause-of-death patterns: **elderly people** suffer the most due to **CVD** and **respiratory diseases**
- However, many other issues of **heatwave impact** on mortality and morbidity **remain controversial**

Heatwave-related mortality disparities

- In spite of **general agreement** among main patterns of heat-related mortality, **significant controversies still persist**:
  - **Spatial disparity: hotter cities** are more **vulnerable** (Ferreira Braga et al. 2001, Grigorieva, Revich, 2021) vs **mortality** is **higher in the North** (Curriero, 2002, Basu, 2009)
  - **Temporal effect**: mortality **lagging** during the heatwave (Rocklov et.al. 2012); **harvesting** effect (Toulemon, Barbieri, 2008)
  - **Socioeconomic determinants**: poverty and social exclusion (Semenza et.al. 1996; Klinenberg, 1999); economic deprivation (Gouveia et al. 2003, Rey et al. 2009); prevalence of air conditioners (Ellis, 1972; Marmor, 1975); heatwave impact prevention
  - **Urban-rural divide** (Rey et al. 2009, Urban et al. 2016) and urban heat island effects (Buechley et al. 1972)

Research questions and problems

- **European Russia was severely hit by 2010 heatwave**: temperature anomalies and smog contributed to significant death rate increase
- However, the problem of heatwave effect on mortality in Russia **remains poorly studied**
- Thereby, little is known about various patterns of death rate increase during 2010 heatwave. Current study aims to:
  - Quantify **excess mortality** during 2010 heatwave
  - Explore **geographical patterns** (**spatial heterogeneity** and **urban-rural** difference) in heat-related death rates
  - Identify **mortality displacement** after the heatwave

Scope of the study

Study area:

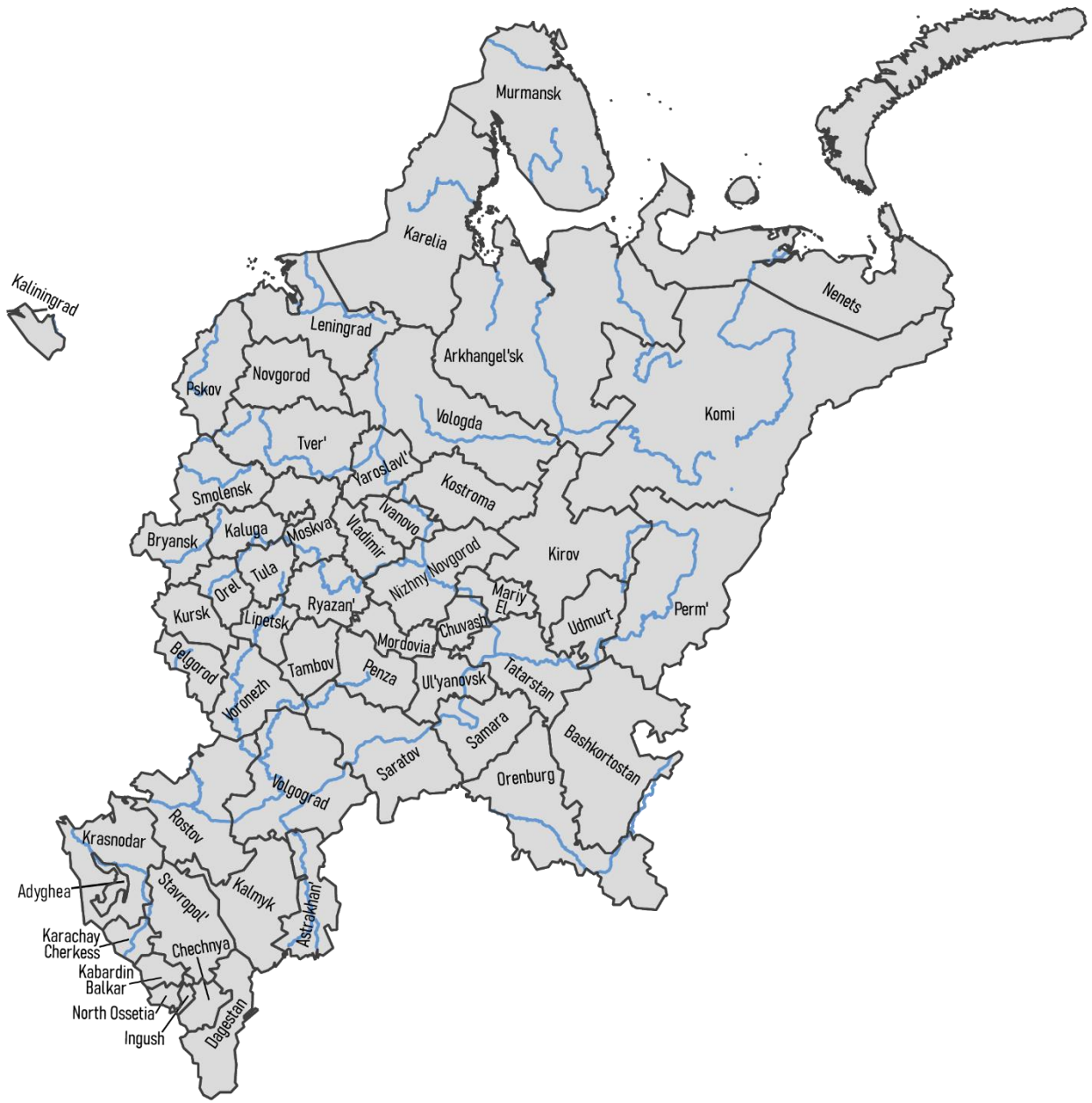
- Urban and rural population in 54 regions of European Russia
- 126 cities with 100,000+ inhabitants

Time period:

- Heatwave limits: 27-33 ISO weeks of 2010 (05.07 – 22.08)
- Reference period: 2005-2009

Data sources:

- Weekly death counts by 5-year age groups for 2005-2010: Rosstat Mortality Microdata
- Age-sex structure by cities: Rosstat
- Age-sex structure by urban and rural population: Russian Fertility and Mortality Database (Center for Demographic Research, Moscow)



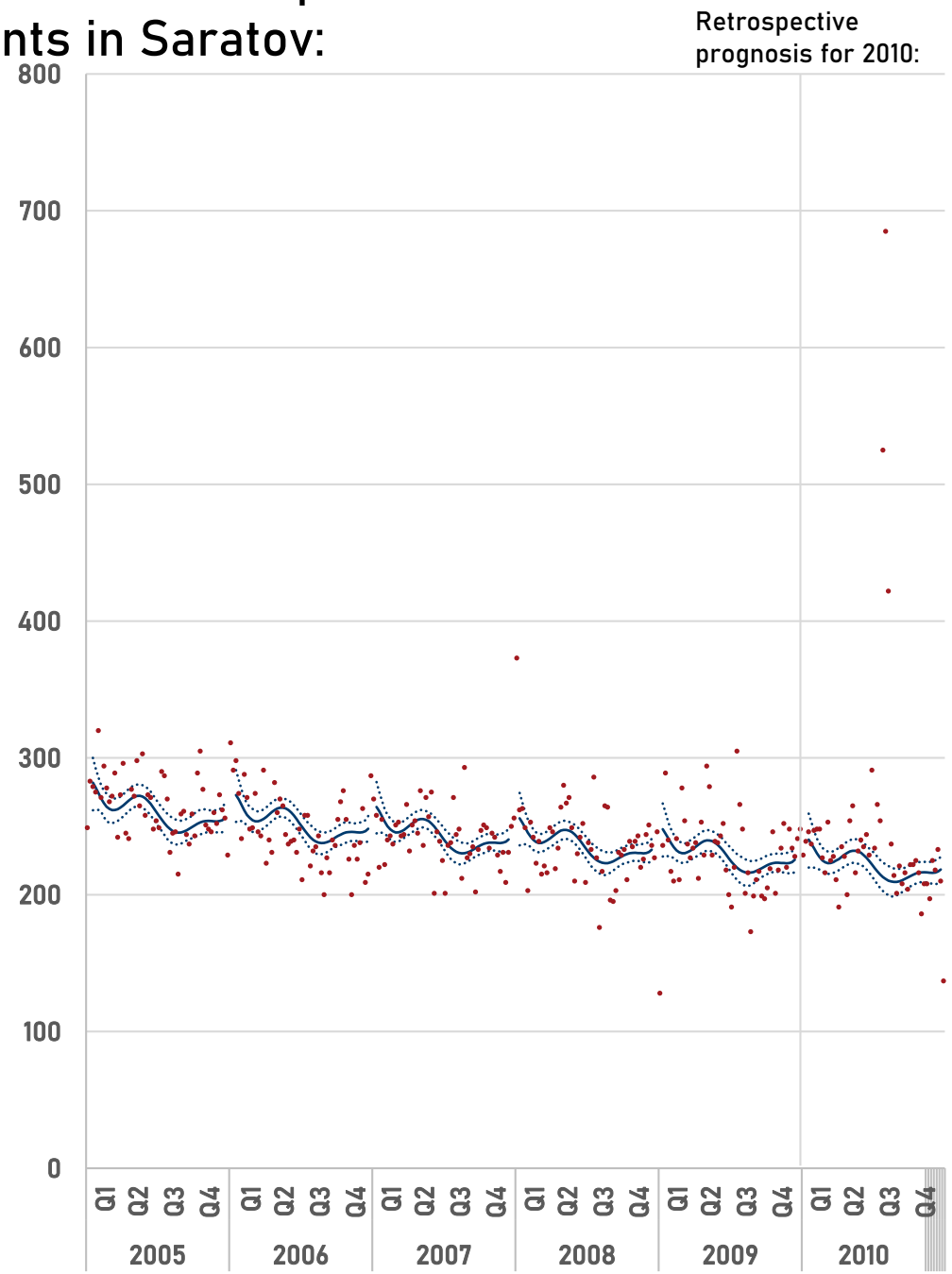
Excess mortality estimation

- Excess is a **difference between observed and expected mortality** estimated by the baseline level model (2005-2009)
- Mortality was assumed in terms of **death counts** and **standardized rates**
- **Negative binomial** regression model selection by **AIC minimization**:

$$log\left(E(d_{week,year})\right) = \beta_0 + \beta_1 y + \beta_2\, bs(week, \quad d = 3, \quad knots = 7) + \beta_3 \sin\left(\frac{2\pi * week}{52}\right) + \beta_4 \cos\left(\frac{2\pi * week}{52}\right) + \beta_5 \sin\left(\frac{2\pi * week}{52}\right) + \beta_6 \cos\left(\frac{2\pi * week}{52}\right)$$

- **Baseline model** includes trend, spline and seasonal components
- **95%CI** were calculated via **bootstrap**

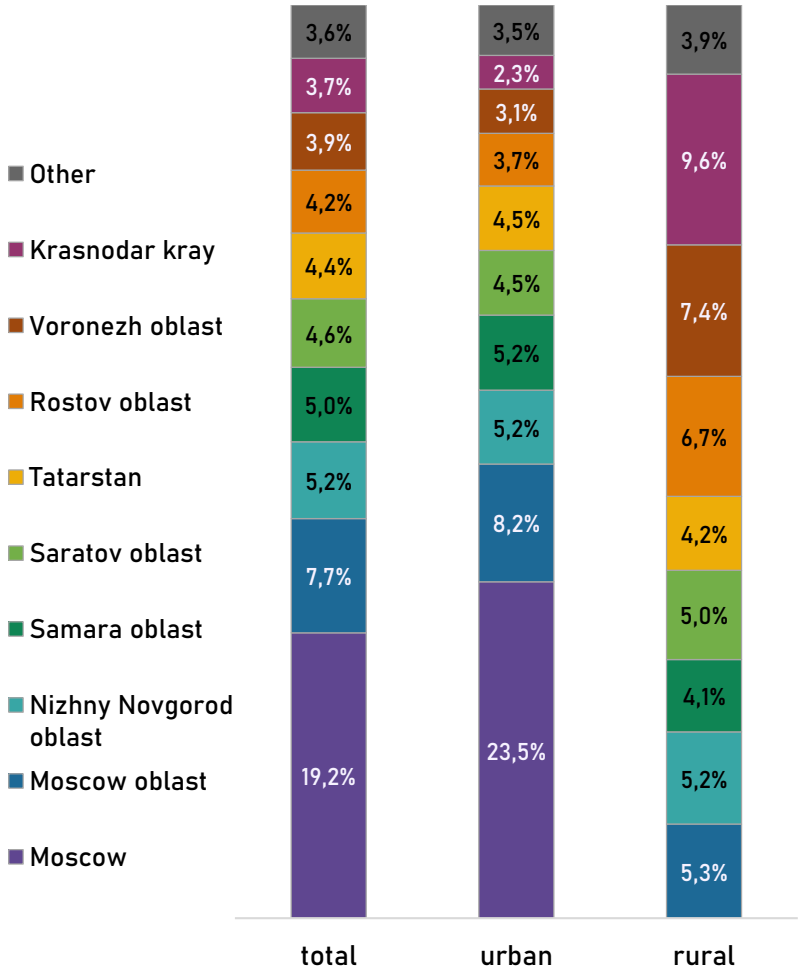
Observed and expected death counts in Saratov:



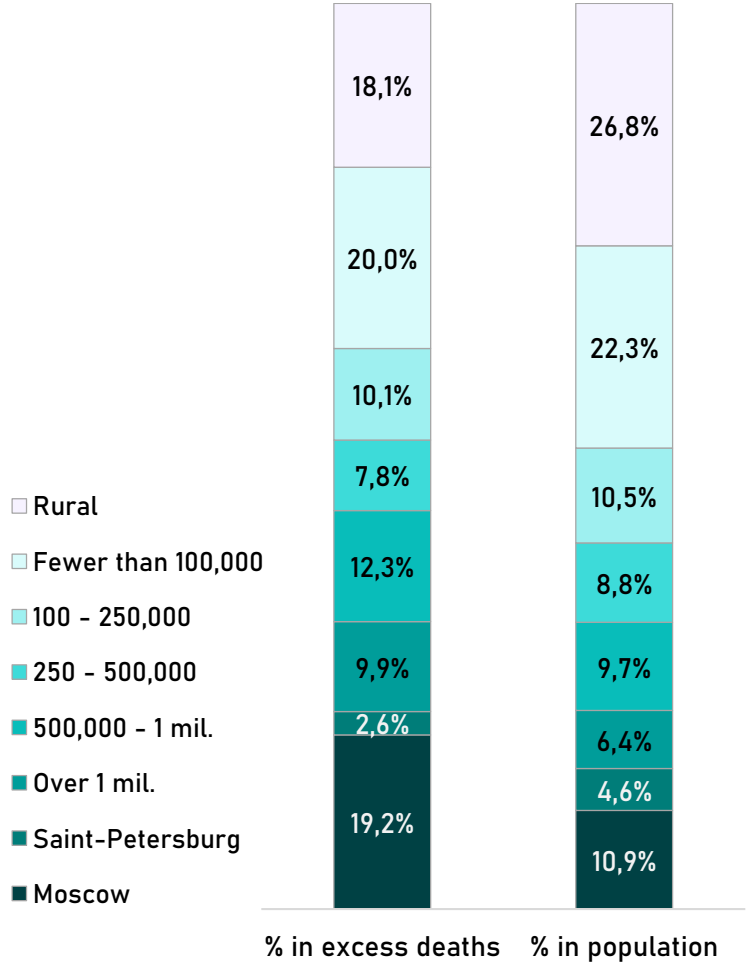
Burden of 2010 heatwave in European Russia

- **57,700 excess deaths** (95% CI: 41,700 – 72,400) during the heatwave resulting in **31,2% increase** (95% CI: 20.7% – 42.6%)
- Regions with the **largest urban agglomerations** contributed the most to excess mortality
- **Urban-rural divide**: 47,200 excess deaths were attributed to cities, 10,400 – to rural areas

Excess death composition by region



Excess deaths and total population composition by type of settlement



Regional patterns of excess mortality

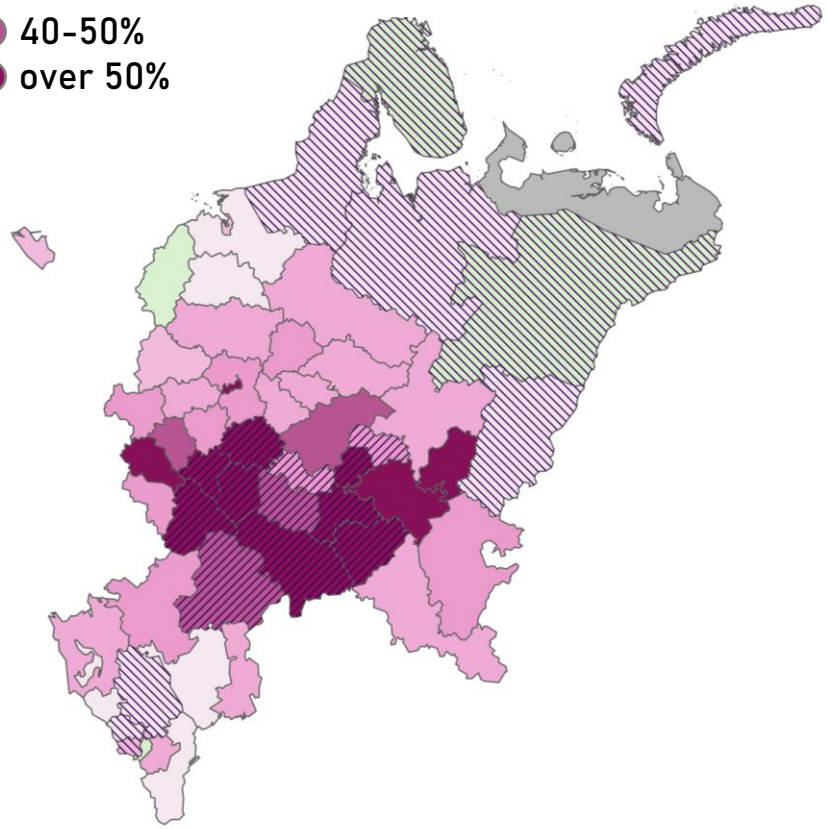
SDR increase during the heatwave:

- less than 0%
- 0-10%
- 10-20%
- 20-30%
- 30-40%
- 40-50%
- over 50%

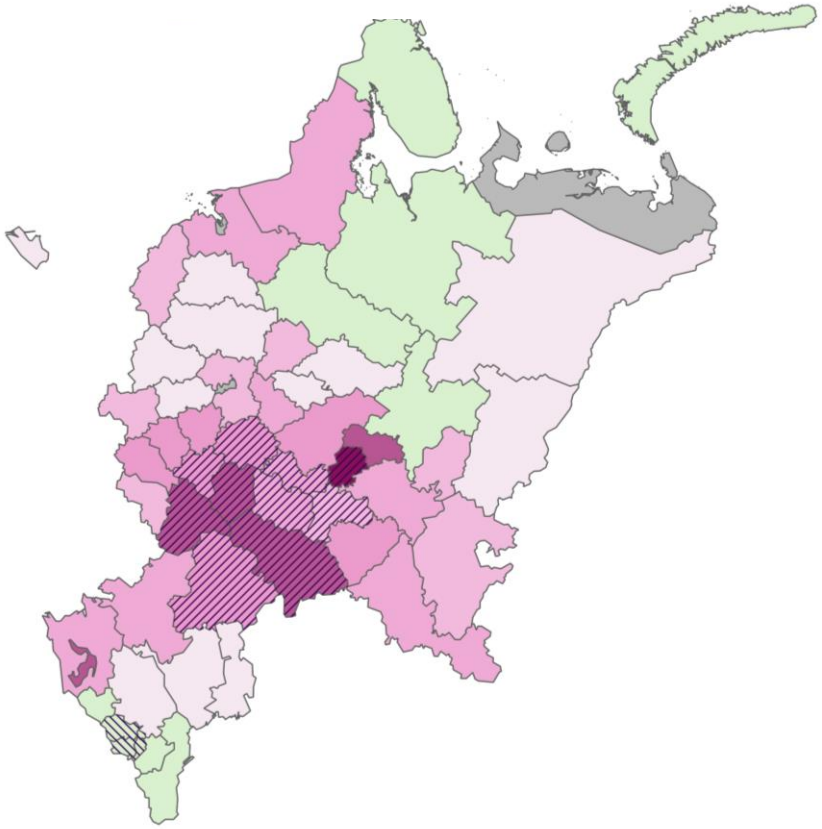
LISA spatial clusters ($p<0.05$):

- high-high
- low-low

Urban:



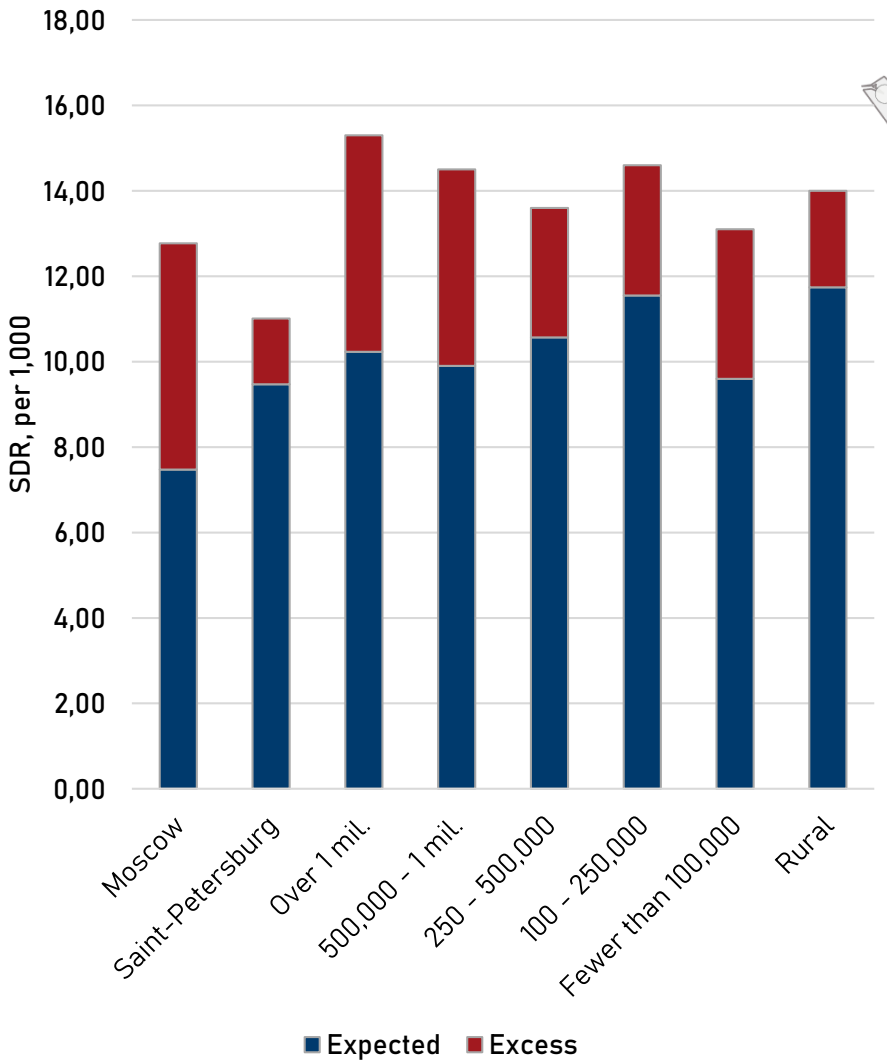
Rural:

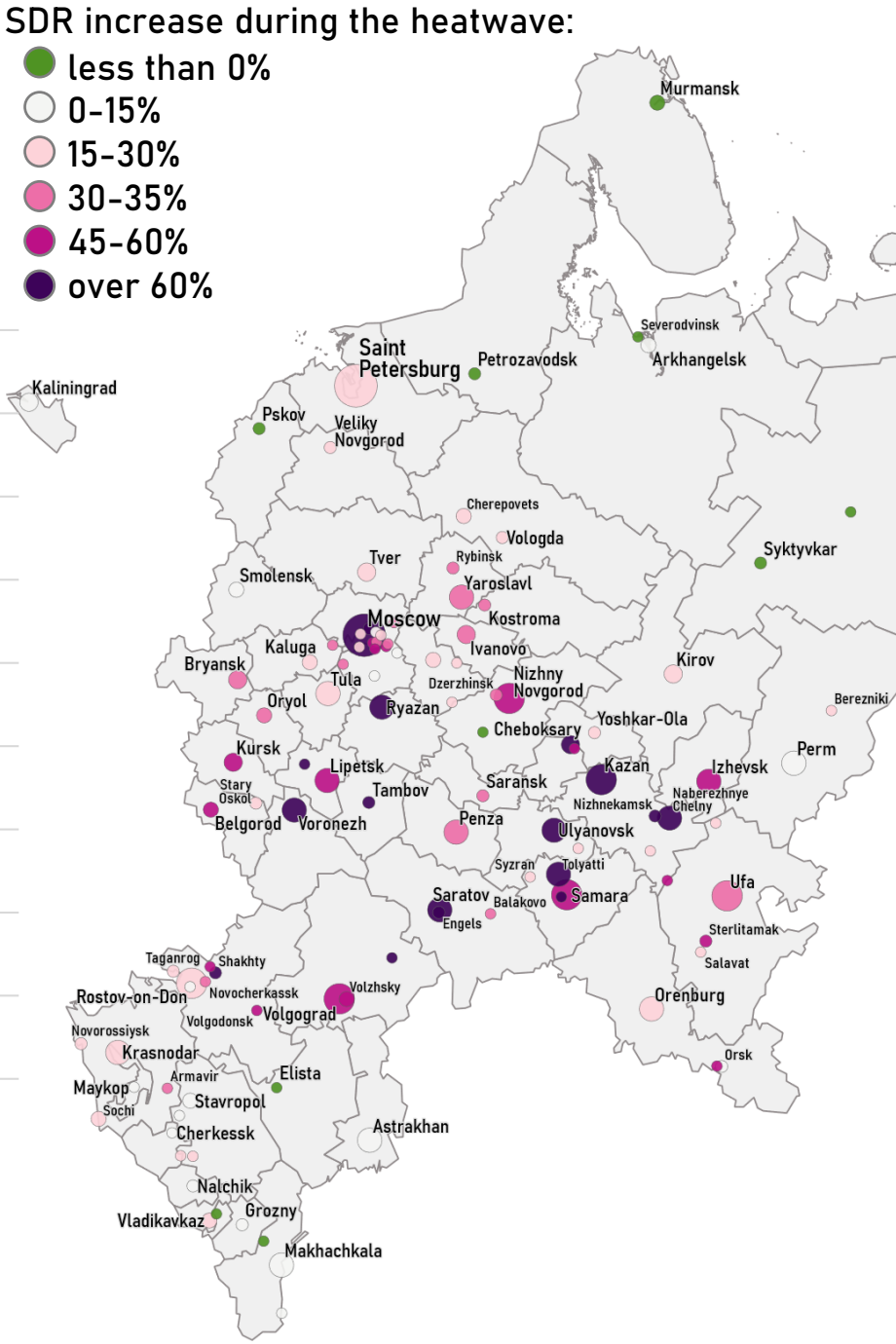


- Death rate increase in rural areas of **Northeast** and **North Caucasus** regions was **statistically insignificant**
- **Middle Volga** and **Black Earth** regions occurred as a **high mortality cluster** for both urban and rural population
- Urban and rural excess mortality have similar **spatial patterns**. However, confidence intervals for **rural population** are much broader

Excess mortality by city size

- The greatest relative increase in ASDR in **cities larger than 500,000** (low-base effects and "urban heat island")
- **"Excess mortality belt"** from Kursk region to Udmurt republic
- Indecisive results for cities with ~100,000 inhabitants





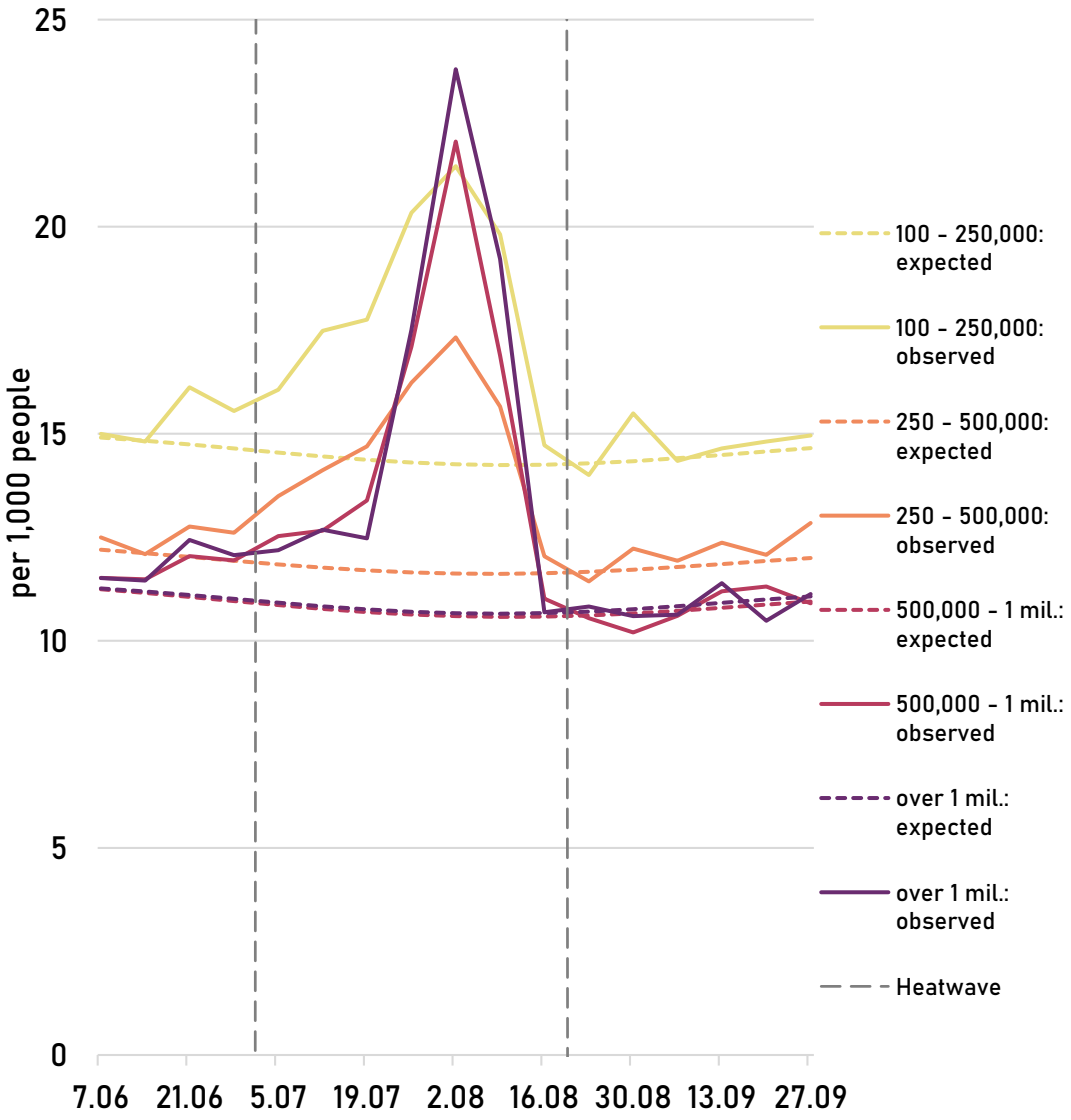
Time-related issues

- **Mortality exceeded the baseline** during the whole period of heatwave
- **28.4%** of excess deaths was concentrated in **31 week** (02-09.08)
- **Mortality fluctuations** were more pronounced in **larger cities**
- **Harvesting** could be probably observed in **most affected cities**

Excess SDR in 20 cities affected the most by the heatwave

	population, 2010	before the heatwave 17.05 - 05.07	heatwave 05.07 - 23.08	after the heatwave 23.08 - 11.10
Kamyshin	119,565	9,93%	84,17%	-2,26%
Lipetsk	508,887	-0,98%	75,95%	2,35%
Saratov	837,900	5,27%	72,41%	-0,32%
Tolyatti	719,632	4,60%	72,38%	0,39%
Cheboksary	447,929	16,38%	69,71%	2,18%
Kazan	1,143,535	5,62%	67,67%	7,38%
Zhukovsky	104,736	18,18%	67,25%	12,02%
Ryazan	524,927	-1,60%	64,29%	-0,20%
Volzhsky	314,255	4,57%	61,93%	-6,40%
Tambov	280,161	8,55%	60,74%	2,78%
Arzamas	106,362	6,75%	59,18%	-1,82%
Ulyanovsk	637,564	3,47%	57,92%	8,39%
Novocheboksarsk	124,097	-4,47%	57,79%	6,55%
Naberezhnye Chelny	513,193	4,91%	57,17%	4,38%
Murom	116,075	4,57%	56,74%	25,93%
Nizhny Novgorod	1,250,619	7,18%	56,35%	2,03%
Dzerzhinsk	240,742	3,59%	56,07%	6,02%
Volgograd	1,021,215	12,09%	55,30%	-4,36%
Yoshkar-Ola	248,782	2,04%	55,15%	-5,80%
Novokuybyshevsk	108,438	14,44%	52,73%	2,64%

Observed and expected SDR in cities by population size



Problems and limitations

- Baseline model assumes **rapid mortality decline** during the **reference period**. That could overstate **excess mortality elevation**
- Due to the small amount of deaths **confidence intervals** for estimates in cities with 100,000 – 200,000 inhabitants were too broad **to provide decisive results**
- **Timeframe** of the study was selected **arbitrarily** due to high weather variability in European Russia. Further discussion is required to define **certain limits of the heatwave**
- **Weekly mortality estimations** do not allow to study **short-term effects**. Daily mortality analysis is required for more precise estimation of temporal effects

Conclusion

- In largest cities (500,000+) population turned out to be more vulnerable to the extremely hot weather
- The revealed urban-rural divide could partially confirm “urban heat island” negative impact on public health and mortality during heatwaves. However, certain risk factors were not defined and assessed
- The greatest excess in mortality was experienced by Black Earth and Middle Volga regions hardest hit by heat wave, whereas Northeast and North Caucasus remained almost unaffected
- On the scope of weeks mortality extremes coincided with temperature records, harvesting were not identified partly to the study limitations