

Heat-related mortality in Europe during 2024 and health emergency forecasting to reduce preventable deaths

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Supplementary Information

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Supplementary Table S1 Characteristics of the daily and weekly mortality database.

	<u>EARLY-ADAPT</u> mortality database			<u>EUROSTAT</u> and national agencies	
	Daily data			Weekly data	
Country	Period	Region level	Attributes	Region level	Stratification
Austria	1974-2020	NUTS3	sex, age	NUTS3	sex, age
Bosnia and Herzegovina	1983-2020	NUTS1		NUTS1 ^c	
Belgium	1992-2021	NUTS3	sex, age	NUTS3	sex, age
Bulgaria	2000-2020	NUTS2	sex, age	NUTS3	sex, age
Switzerland	1969-2021	NUTS2	sex, age	NUTS3	sex, age
Cyprus	2004-2020	NUTS3	sex, age	NUTS3	sex, age
Czechia	1994-2021	NUTS3	sex, age	NUTS3	sex, age
Germany	2000-2022	NUTS1		NUTS1	
Denmark	2007-2020	NUTS1	sex, age	NUTS3	sex, age
Estonia	1994-2021	NUTS2	sex, age	NUTS2	sex, age
Greece ^a	1999-2018	NUTS3	sex, age	NUTS3	sex, age
Spain	1980-2018	NUTS3	sex, age	NUTS3	sex, age
Finland	1990-2021	NUTS2	sex, age	NUTS2	sex, age
France	1972-2021	NUTS3	sex, age	NUTS3	sex, age
Croatia	1983-2020	NUTS1	sex, age	NUTS1	sex, age
Hungary	1990-2020	NUTS2	sex, age	NUTS3	sex, age
Ireland	2000-2020	NUTS1	sex	NUTS1	sex
Italy	2004-2019	NUTS3	sex, age	NUTS3	sex, age
Lithuania	1993-2020	NUTS2	sex, age	NUTS3	sex, age
Luxembourg	1998-2020	NUTS3	sex, age	NUTS3	sex, age
Latvia	2000-2021	NUTS3	sex, age	NUTS3	sex, age
Montenegro	2006-2021	NUTS3	sex, age	NUTS3	sex, age
Netherlands	1995-2021	NUTS0	sex	NUTS3	sex
Norway	1962-2020	NUTS3	sex, age	NUTS3	sex, age
Poland	2000-2020	NUTS3	sex, age	NUTS3	sex, age
Portugal ^a	1980-2018	NUTS2	sex, age	NUTS2	sex, age
Romania	1994-2020	NUTS3	sex, age	NUTS3	sex, age
Serbia	2000-2020	NUTS3	sex, age	NUTS3	sex, age
Sweden	1969-2022	NUTS1	sex, age	NUTS3	sex, age
Slovenia ^b	1997-2021	NUTS3	sex	NUTS1	sex
Slovakia	1996-2021	NUTS3	sex, age	NUTS3	sex, age
UK - England and Wales	1981-2020	NUTS1	sex, age	NUTS1	
UK - Northern Ireland	1975-2023	NUTS2		NUTS2	
UK – Scotland ^b	1990-2020	NUTS3	sex, age	NUTS1	

^a The most recent 5-year period (i.e. 2014-2018) was used to calibrate epidemiological models.

^b Weekly mortality data at higher NUTS level was distributed among lower NUTS levels using mortality pattern observed during the calibration period (2015-2019).

^c Daily data was available for 2022 and 2023. Only monthly data was available for 2024. Monthly data was transformed to daily data using monthly cycle observed during the calibration period (2015-2019).

EARLY-ADAPT mortality database

We would like to acknowledge the following data providers of the daily EARLY-ADAPT mortality database:

1. Statistics Austria
2. Agency for Statistics of Bosnia and Herzegovina (BHAS)
3. Directorate-General Statistics - Statistics Belgium (Statbel)
4. National Statistics Institute of Bulgaria (NSI)

5. Federal Statistical Office of Switzerland (FSO): *"Federal Statistical Office, data from causes of death statistics 1969-1994 / 1995-2020 / 2020 and so on"*
6. Health Monitoring Unit of the Ministry of Health of Cyprus: *"The data used in this study was collected by the Health Monitoring Unit of the Ministry of Health of Cyprus. The ideas and opinions expressed herein are those of the author. Endorsement of these ideas and opinions by the Ministry of Health of Cyprus is not intended nor should it be inferred"*
7. Institute of Health Information and Statistics of the Czech Republic (UZIS)
8. German Federal Statistical Office (Destatis): *"German Federal Statistical Office (Destatis). [Data licence Germany – attribution – Version 2.0. Statistischer Bericht - Sterbefälle nach Tagen, Wochen und Monaten - endgültige Daten - 2000 bis 2019](#) and [Statistischer Bericht - Sterbefälle nach Tagen, Wochen und Monaten - 2020 bis 2024](#)"*
9. Statistics Denmark (DST)
10. National Institute for Health Development of Estonia (TAI): *"National Institute for Health Development of Estonia (TAI) - Estonian Causes of Death Registry"*
11. Hellenic Statistical Authority (ELSTAT)
12. National Statistics Institute of Spain (INE)
13. Statistics Finland
14. French National Institute for Statistics and Economic Studies (INSEE)
15. Croatian Bureau of Statistics (DZS)
16. Hungarian Central Statistical Office (HCSO): *"Aggregated data on daily mortality for Hungary. Datafile prepared upon individual request by the Hungarian Central Statistical Office (www.ksh.hu)"*
17. Central Statistics Office Ireland (CSO)
18. Italian National Institute of Statistics (ISTAT)
19. Institute of Hygiene of Lithuania
20. Ministry of Health of Luxembourg
21. Centre for Disease Prevention and Control of Latvia (SPKC): *"Register of Causes of Death, Centre for Disease Prevention and Control of Latvia (SPKC)"*
22. Statistical Office of Montenegro (MONSTAT)
23. Statistics Netherlands (CBS)
24. Norwegian Institute of Public Health (FHI): *"Norwegian Cause of Death Registry / Norwegian Institute of Public Health (FHI)"*
25. Statistics Poland
26. National Statistics Institute of Portugal (INE)
27. Instituto Nacional de Estatística - Portugal (Statistics Portugal): *"Instituto Nacional de Estatística - Portugal (Statistics Portugal), Number of deaths by place of residence, sex and age group; 1980-2018"*
28. National Institute of Statistics of Romania (NIS Romania): *"National Institute of Statistics of Romania (NIS Romania), Statistical Survey on Mortality"*
29. Statistical Office of the Republic of Serbia
30. National Board of Health and Welfare of Sweden (Socialstyrelsen): *"Swedish Cause of Death Register, National Board of Health and Welfare"*
31. National Institute of Public Health of Slovenia (NIJZ)
32. Statistical Office of the Slovak Republic
33. Office for National Statistics of the United Kingdom (ONS)
34. Northern Ireland Statistics and Research Agency (NISRA)
35. National Records of Scotland (NRS)

Supplementary Table S2 First-stage sensitivity analysis.

Baseline Model	Attributable Number (deaths), Summer 2024
Exposure-Response Function: Natural Cubic Spline, Knots at Percentiles P10, P75, P90 Natural Cubic Spline of Time to Control for Seasonal and Long-term Trends: 8 df/year	62,775 (36,765-84,379)
Alternative Models	
Exposure-Response Function: Knots at Percentiles P10, P50, P90	64,746 (52,971-75,242)
Exposure-Response Function: Knots at Percentiles P10, P25, P75, P90	63,488 (38,621-85,599)
Exposure-Response Function: Knots at Percentiles P10, P25, P50, P75, P90	64,697 (40,187-85,170)
Exposure-Response Function: B-spline of degree 2	60,843 (37,902-81,159)
Natural Cubic Spline of Time to Control for Seasonal and Long-term Trends: 7 df/year	59,830 (35,642-79,810)
Natural Cubic Spline of Time to Control for Seasonal and Long-term Trends: 9 df/year	61,709 (50,675-71,548)

Values correspond to heat-related mortality number during the summer of 2024 in Europe, and their corresponding 95% confidence intervals. Summer refers to the period between 1 June and 30 September.

Supplementary Table S3 Second-stage sensitivity analysis.

Model	Meta-Predictor	Wald Test	Q Test	I² (%)
Intercept Only	/	/	< 0.001	41.3
Single Predictor	Temperature Average	< 0.001	< 0.001	33.4
	Temperature Interquartile Range	< 0.001	< 0.001	40.6
	Percentage of People Aged 80+	0.001	< 0.001	38.1
Baseline Model	Temperature Average	< 0.001	< 0.001	30.5
	Temperature Interquartile Range	< 0.001		
	Percentage of People Aged 80+	< 0.001		

Supplementary Table S4 Sensitivity analysis of weekly data utilization.

Database temporal resolution for Heat Attributable Number calculation	Average Annual Heat Attributable Number (deaths), Summer 2015-2019
Daily	40,461 (22,321-55,511)
Weekly	40,239 (22,180-55,216)

Values correspond to average annual heat-related mortality number during the summers of 2015-2019 in Europe, and their corresponding 95% confidence intervals. Summer refers to the period between 1 June and 30 September.

Supplementary Formulae S1-2 Calculation of True Positive Rate and False Positive Rate.

For each day and lead time t , we calculated the proportion of 5,100 samples (uncertainties from epidemiological models = 100 Monte Carlo simulations × uncertainties from weather forecasts = 51 ensemble members) exceeding the heat-related mortality emergency threshold. We selected decision threshold i and classified each day as an emergency or non-emergency day comparing the calculated proportion with decision threshold i . True positive rate (TPR) and false positive rate (FPR) were calculated for each lead time t , region r and decision threshold i using the standard formula:

$$TPR_{tri} = \frac{TP_{tri}}{TP_{tri} + FN_{tri}}$$

$$FPR_{tri} = \frac{FP_{tri}}{FP_{tri} + TN_{tri}}$$

where:

- TP (True Positives) is a number of days of a time series correctly forecasted as emergency,
- FN (False Negatives) is a number of days of a time series incorrectly forecasted as non-emergency,
- FP (False Positives) is a number of days of a time series incorrectly forecasted as emergency, and
- TN (True Negatives) is a number of days of a time series correctly forecasted as non-emergency.