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Rethinking early warning systems for the health effects of extreme heat

Climate change is the greatest threat to global health and wellbeing in the 21st century. Strong evidence shows that heat exposure largely increases the risk of death and morbidity, especially among socioeconomically disadvantaged individuals, women and older individuals[1]. Globally, half a million deaths are associated with heat each year[2]. Since the summer of 2003 (when Europe experienced a historic hot season that led to more than 70,000 excess deaths)[3], heat has been a growing concern for governments and public health agencies. A recent study found that despite two decades of adaptation efforts[4], high mortality figures similar to those in 2003 occurred in 2022, 2023 and 2024 (in total, 181,446 heat-related deaths)[5]. In light of this, developing innovative tools for the real-time monitoring and forecasting of heat-related health outcomes is critical for effective public-health protection and resource allocation.

The European Environment Agency recently outlined the status of health-impact surveillance and actions plans in 38 European countries, and focused on forecasting to mobilize resources, monitoring to support rapid decision-making, and post-event evaluation to support longer-term decision-making[6]. The implementation of these complementary components requires access to high-quality health data. However, although the openness and availability of health data are fundamental to enable retrospective monitoring[7], they are not sufficient on their own to effectively protect the population from forthcoming extreme events. To address this issue, heat actions plans must include real-time forecasts of the nearby future heat-related mortality — typically with lead times of up to 1 or 2 weeks, which are those relevant for public health management and preparedness. Importantly, these are the lead times at which health emergencies can be forecast with high confidence, which generates trust among public health agencies and decision-makers[5,8]. Furthermore, to facilitate comparisons across countries, regions and cities, it is necessary to adopt a standardized methodology, not only in weather forecasting and epidemiological modelling but also to assist in communication of warnings within and across countries. This includes the standardization of methodologies and warning criteria based on state-of-the-art epidemiological research, including definitions of, for instance, what is understood as moderate or extreme heat effects on health in each location and population group. Unfortunately, neither are open high-quality health data available nor is a common methodology used, even in the European context.

To highlight methodological heterogeneity in estimating the health burden of extreme temperatures, we compiled national estimates from public health agency reports and academic articles for the record-breaking summer of 2022 in Europe. Table 1 compares available estimates for nine countries with those recently published in ref. 5, which were based on a very large daily temperature and mortality database fitted with a single state-of-the-art epidemiological methodology (in this case, quasi-Poisson models combined with distributed lag nonlinear models)[5]. Most estimates came from national public health or statistical agencies; four countries also had academic estimates that often diverged from official reports. For example, in Germany, public authorities estimated a total of about 4,700 excess deaths, whereas academic estimates raised the burden to over 9,000 heat-related deaths. Similarly, in Spain, the burden from the public health agency underestimated values from academic studies by up to 60%. Data sources varied, from daily to weekly mortality data, and the description of the methodology was unclear or imprecise in some countries; methods ranged from excess mortality approaches to quasi-Poisson models with distributed lag nonlinear models. In almost all of the analysed countries, the focus was on evaluating the health effects of heat via annual or seasonal reports to inform future actions, rather than being oriented towards real-time day-to-day monitoring or forecasting. Although public health agencies are likely to internally monitor the health effects of heat in real time, public reporting of heat-related deaths is largely directed towards summarizing the burden at the end of the summer season.

Most heat-related deaths are probably preventable[9]. The adaptive capacity to prevent them depends on the existence and implementation of strategies designed to predict, detect and respond to heat episodes, including the use of early warning systems. The United Nations has launched the 'Early Warnings for All' initiative, which aims at ensuring universal protection from hazardous climate-related events through life-saving multihazard early warning systems. However, although this and other similar strategies (for example, EUMETNET's Meteoalarm) are essentially based on predicting the occurrence of natural hazards such as heat episodes, modelling and forecasting their health effects should also be considered as a key intrinsic component of early warning systems. The use of epidemiological models to anticipate the burden in vulnerable groups is a major advantage of this approach (for example, Forecaster.health), so that public health resources are allocated where they are most needed, and target and prioritize at-risk populations. Early warnings were indeed available multiple days in advance of the early European heatwave of late June 2025, with, for example, widespread extreme alerts for women and older individuals in southern and western Europe, but mostly low-to-high warnings for men and younger adults (see the 'Surveillance' section of Forecaster.health). The availability and use of this kind of information is only possible through the co-design and co-development of tailored climate services for health, which, as of today, are infrequent in high-income countries and non-existent in low-resource settings[10]. As shown in Table 1, there is an urgent need to define and use robust standardized methodologies applied to open high-quality health data, which is lacking in the parts of the world where health protection strategies are most needed[9]. Recent advancements in epidemiological modelling have succeeded in providing vulnerability estimates in low-resource and rural settings[11], which — combined with existing global weather forecasting systems — have the capacity to generalize impact-based early warning systems worldwide. In the current urgent context of climate change, it is better

Table 1 | Comparison of heat-related mortality estimates for the summer of 2022 in Europe

Country		Janoš et al.[5]	Other reports			
		2022 estimate	2022 estimate	Estimate period	Source type	Method
Austria		574 (176, 902)	231 (−31, 493)	23 May–2 October	Public health agency	Excess mortality
Belgium[12]		631 (171, 1,027)	2,311	16 May–9 October	Public health agency	Excess mortality, quasi-Poisson
France		5,839 (1,882, 9,189)	10,420	1 June–15 September	Public health agency	Excess mortality
			6,969 (6,277, 7,445)	1 June–15 September	Academic	Quasi-Poisson DLNM
Germany	Source 1	9,636 (7,154, 11,899)	About 4,700 (3,100, 6,300)	11 April–9 October	Public health agency	Unclear
	Source 2 (ref. 13)		About 9,100 (7,300, 10,700)	1 May–30 September	Academic	Quasi-Poisson DLNM
Italy[14]		18,801 (13,761, 23,133)	6,858	16 May–16 September	Public health agency	Excess mortality, 49 major cities (not whole country)
Portugal		1,622 (1,155, 2,009)	4,145	23 May–19 June, 4 July–7 August	Public health agency	Excess mortality
Spain	Source 1 (ref. 15)	12,135 (8,207, 15,431)	4,744	1 June–30 September	Public health agency	Poisson GAM
	Source 2 (ref. 16)		12,054	1 June–31 August	Academic	Quasi-Poisson DLNM
Switzerland	Source 1	522 (102, 871)	474 (271, 674)	1 May–30 September	Public health agency	Quasi-Poisson DLNM
	Source 2 (ref. 17)		623 (151, 1,068)	1 June–31 August	Academic	Quasi-Poisson DLNM
UK	Source 1	2,783 (−170, 5,238)	3,271	1 June–31 August	National statistical agency	Excess mortality, England and Wales
	Source 2		2,985 (2,258, 3,712)	1 June–15 September	Public health agency	Excess mortality, England

National estimates (units: deaths) are shown for ref. 5, and for heterogeneous reports from public health agencies, national statistical agencies and academic publications, together with their estimation period and methodological approach. Values in parenthesis show the 95% confidence interval, if available. Data sources are hyperlinked or cited in their respective cells. DNLM, distributed lag nonlinear model; GAM, generalized additive model.

to integrate available scientific evidence and methodologies so that it is possible to anticipate and respond to the health effects of heat quickly and effectively. We therefore call on meteorological, public health and statistical agencies to promote the standardization and adoption of existing advanced epidemiological methodologies to integrate weather and health forecasting into early warning system strategies, and to prioritize the implementation of these tools in the most vulnerable countries, communities and population groups.

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Competing interests

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