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China's pioneering heat-health warning system: A critical leap and future agenda

Guanhao He,[1] Jianxiong Hu,[1] and Wenjun Ma[1,*]

[1]Department of Public Health and Preventive Medicine, School of Medicine, Jinan University, Guangzhou 510632, China

*Correspondence: mawj@gdiph.org.cn

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With climate change, the frequency and intensity of heatwaves are steadily increasing. On July 27, 2023, UN Secretary-General António Guterres issued a stark warning in response to unprecedented global heat, declaring, "The era of global warming has ended; the era of global boiling has arrived." The Copernicus Climate Change Service, the European Union's climate monitoring agency, announced that the global surface average temperature reached 15.10°C in 2024, surpassing the previous record set in 2023 by a margin of 0.12°C and exceeding the pre-industrial baseline (1850-1900) by 1.6°C. According to the Global Burden of Disease in 2021, high temperatures contributed to over 440,000 deaths globally.[1] Therefore, it is imperative to effectively adapt to climate change and mitigate related health burden.

As an emerging economy with the world's largest population and pronounced geographical/climatic heterogeneity, China is facing a substantial health challenge from heatwaves. In 2021 alone, high temperatures were associated with around fifty thousand deaths in China, accounting for more than one-tenth of the global total.[1] The Chinese government places high priority on climate change adaptation. It released the *National Climate Change Adaptation Strategy 2035* in 2022 and the *National Climate Change Health Adaptation Action Plan (2024-2030)* in 2024.[2,3] On July 2, 2025, a significant milestone was reached when the National Disease Control and Prevention Administration (NDCPA) and the China Meteorological Administration (CMA) jointly issued China's first nationwide Heat-Health Risk Warning.[4] This marks a crucial step forward in multi-sectoral collaboration within China's climate change health adaptation efforts.

The heat-health warning system (HHWS) categorizes health risk into five levels (Low, Medium, Elevated, High, Extreme), as shown in Figure 1. These thresholds are regionally specific, derived from statistical models (such as distributed lag linear model or generalized additive model) that analyze the association between temperature and mortality across China's diverse climate zones. Accompanying the warning are health protection guidance recommendations tailored to each risk level. Warnings are disseminated through multiple channels, including China Central Television (CCTV), the National Emergency Warning Information Release System, and various new media platforms.

Compared with international HHWSs, such as those implemented in Europe and the United States,[5] China's system shares the overarching objective of reducing heat-related health impacts but exhibits distinct operational characteristics. This divergence can be structured along four key dimensions: risk definition, threshold adjustment, the integration of vulnerability, and cross-sector collaboration. First, regarding risk definition, while many systems abroad have adopted health-impact frameworks, China's approach distinguishes itself by its systematic and standardized nationwide application. Second, in terms of threshold adjustment, instead of applying a centralized national system or isolated city-level initiatives, China's system accounts for regional climatological and demographic heterogeneity. Its approach is established through a macro-scale epidemiological temperature-mortality model, applied to high-resolution meteorological data to calibrate local thresholds for precise warnings. Furthermore, the Chinese central government also encourages the development of provincial-level warning systems. Several provinces, including Zhejiang, Hunan, Hubei, and Guangdong, have established their own localized systems. Third, a key innovative feature of China's system is the integrated dissemination of actionable guidance, especially for vulnerability. Each warning is coupled with specific protective recommendations tailored to vulnerable groups, such as the elderly, pregnant women, children, individuals with chronic diseases, and outdoor workers. This moves beyond general public advisories towards targeted, group-specific intervention protocols. Fourth, the system exemplifies institutionalized cross-sector collaboration between health and meteorological departments, featuring a cooperative mechanism for data sharing, joint warning issuance, and coordinated response. In summary, the Chinese model's significance lies in its systematic integration of health-based risk definition, regionally adaptive thresholds, targeted vulnerability management, and cross-sector collaboration. This structured approach offers a complementary and potentially generalizable framework for enhancing early warning precision and public health relevance in other large, geographically diverse nations.

Establishing a HHWS offers significant advantages, but it requires careful governance to balance these benefits against related operational tensions. For instance, while the system enables timely public health interventions through earlier alerts, this introduces a core trade-off: increasing alert frequency to ensure timeliness can lead to public alert fatigue and reduced response effectiveness. Moreover, while a nationally constructed warning system guarantees standardized alerts, this very uniformity can create an inherent trade-off, as it may not align with local response capacities and specific vulnerability patterns. Furthermore, the system promotes valuable interagency coordination between meteorological and health authorities, such multi-sectoral governance introduces operational complexities, such as aligning objectives, timelines, and resources.

Therefore, multi-sector heat-health warnings only represent the initial step in health adaptation. To more effectively mitigate the health risks of climate change in the future, a comprehensive adaptation framework should be developed, which may include the following:

(1) Develop national and corresponding regional heat-health adaptation plans

A national heat-health adaptation plan should be developed and implemented in coordination with local adaptation plans. These plans include heat-health early warning, urban planning, community participation, risk communication, and targeted protection for vulnerable populations, with particular attention to disparities in heat exposure and adaptive capacity arising from urban-rural divides and socioeconomic inequalities, factors that constitute key dimensions of individual vulnerability. To prevent the system from unintentionally exacerbating health inequities, the multi-level planning framework must explicitly address the practical constraints in aging societies and regions with sharp urban-rural divides, such as through differentiated funding mechanisms, capacity-building in low-resource communities, and equity-focused performance monitoring.

(2) Evaluate system effectiveness with an equity lens

Evaluate the effectiveness of HHWS from the perspectives of the public awareness, behavioral change, and cost-effectiveness to identify strengths and weaknesses of HHWS for evidence-based continuous improvement. This evaluation must clearly distinguish between the system's inherent design advantages and its empirically verified health benefits. While the institutional design holds promise for reducing risk, a systematic assessment of its actual impact on morbidity, mortality, and medical burden is necessary to confirm its real-world public health value. Key performance indicators of HHWS may include changes in heat-related morbidity and mortality, the adoption rate of recommended protective measures among the general public and vulnerable groups, shifts in healthcare utilization during heat alerts, and the equity of outcomes across different regions and socioeconomic strata. Evaluation should also focus on whether the HHWS mitigates or exacerbates health disparities amid aging populations and urban-rural divides, and assess the gap between alert issuance and actual protective action in resource-limited communities. Focusing on these indicators will yield a precise assessment of the system's real-world public health impact and provide a clear roadmap for its ongoing refinement.

(3) Personalized warnings: navigating technical and data complexity

The current HHWS only provides static, population-wide heat-health warn-

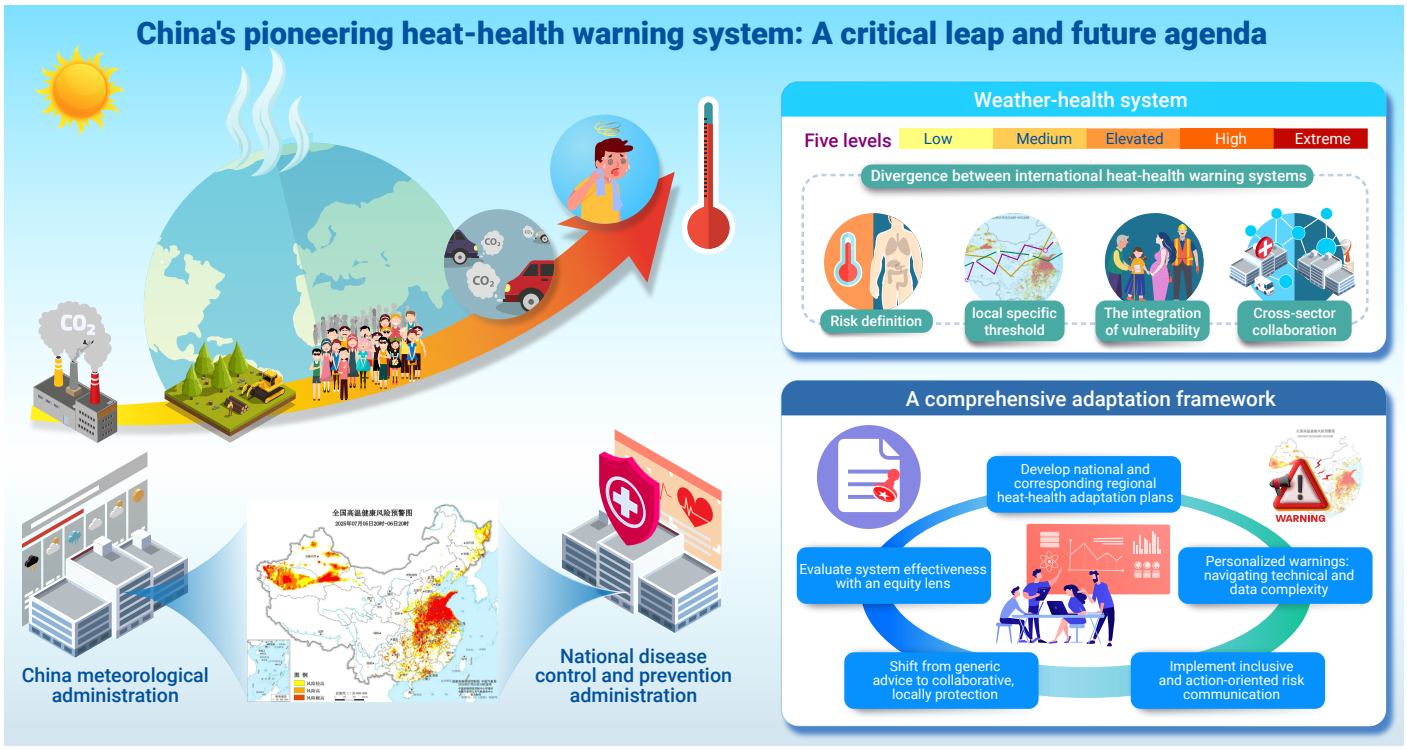

Figure 1. China's pioneering heat-health warning system: a critical leap and future agenda.

ings based on ambient temperature-mortality relationships, lacking granularity to account for individual-level vulnerability factors. Future iterations should therefore prioritize integrating such multidimensional vulnerability data (such as population structure, socio-economic indicators, chronic disease information), and applying advanced technical frameworks (such as machine learning, multi-dimensional exposure models, or risk scoring systems). This will facilitate dynamic, personalized risk assessments, moving beyond broad demographic categories towards truly individualized early warning. It is worth noting that this implementation must be carefully designed to prevent data and technical demands from widening disparities between well-resourced and under-resourced populations and regions.

(4) Shift from generic advice to collaborative, locally protection

Current risk-level-based protection advice is often too generic and focuses heavily on individual self-protection, and future guidance should emphasize the critical roles of governments, communities, and Non-Governmental Organizations (NGOs) in health adaptation, especially in addressing the unequal distribution of adaptive resources across different regions and social groups and supporting individuals with high vulnerability scores identified by refined warning models. A key practical challenge lies in ensuring that alerts trigger effective responses in low-resource and rural settings, where infrastructure, funding, and institutional capacity may be limited. Concrete measures could include: governments establishing public cooling centers and enacting occupational health regulations for outdoor workers, and investing in urban design such as expanding green and blue spaces to mitigate the urban heat island effect; NGOs leading targeted risk communication campaigns and providing assistance to economically disadvantaged households; and communities organizing regular wellness checks by volunteers, providing accessible cooling spaces, and facilitating health guidance from community-based primary care providers to strengthen grassroots health support. To overcome implementation gaps, link early warnings to pre-allocated local response resources, strengthen community-led adaptation networks, and ensure that external support reaches the most vulnerable subgroups and areas.

(5) Implement inclusive and action-oriented risk communication

Strengthen risk communication to improve public understanding of warning signals to drive behavioral change, enhance adaptive capacity, and ultimately reduce health risks. Communication strategies must be tailored to the needs of an aging population and urban-rural gaps in access, literacy, and trust. For older populations and low-resource areas, strategies such as community voice messages, local trusted messengers, and low-tech channels should ensure warnings prompt timely action, not just information delivery.

In conclusion, China's HHWS offers a valuable reference model for large, diverse nations, integrating health risk, regional adaptation, and cross-sector collaboration. Its experience provides relevant lessons for other climate-vulnerable and urbanizing regions, especially in low- and middle-income countries, advancing global climate-health resilience.

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AUTHOR CONTRIBUTIONS

Guanhao He: Conceptualization, Writing - Original Draft. **Jianxiong Hu:** Writing - Original draft. **Wenjun Ma:** Conceptualization, Writing - Review and Editing, Supervision. All authors contributed to and approved the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.