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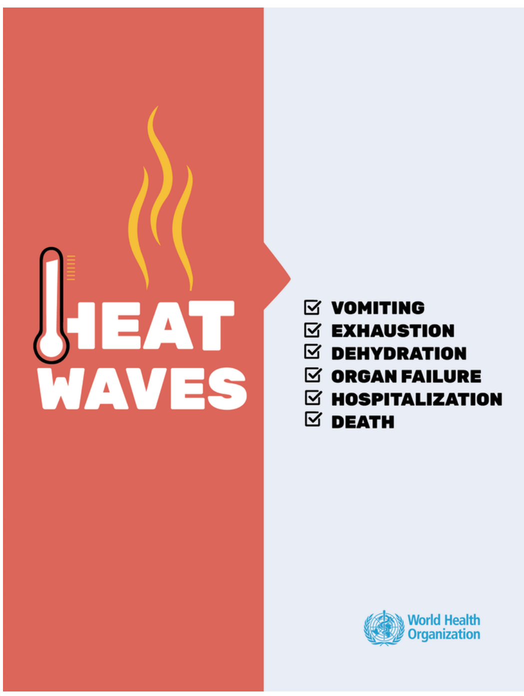

HEAT HEALTH RISK EARLY WARNING ISSUE

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Cover Image: adapted from the World Health Organization, https://www.who.int/multi-media/details/heat-waves.
This week's issue was organized by Guest Editor Tiantian Li.

Foreword

A Public Health Initiative for Action on Early Warning of Heat Health Risks

Tiantian Li[1,#]

Heatwaves, also known as extreme heat events, represent periods of excessively hot weather and rank among the most perilous natural hazards worldwide due to their increased mortality risk, especially among vulnerable populations. The frequency, intensity, and geographical spread of heatwaves are noticeably increasing in the setting of climate change (*1*). In 2019, there were a reported 475 million heatwave events worldwide, an increase of 160 million per capita days in comparison to 2016 (*2*). Disturbingly, in 2003 there were approximately 25,000–70,000 premature heat-related deaths in Western Europe (*3*), and in the summer of 2010 around 55,000 excess deaths in Russia were linked to heatwaves (*4*). A similar pattern was observed in 2019 with approximately 26,800 deaths in China being attributed to heatwaves (*5*). Furthermore, in the same year, nearly half (46.2%) of the total global heat-related deaths were elderly individuals, with the majority of these deaths occurring in Japan, Eastern China, Northern India, and Central Europe (*6*). Given the relentless trends in population aging and urbanization, heatwaves could pose a significantly bigger health hazard in future years. Projections from the World Health Organization (WHO) predict over 92,000 premature deaths from high temperatures globally by 2030, with over 19,000 premature deaths expected in Eastern Asia (inclusive of China and the Republic of Korea) alone (*7*). Hence, the development and implementation of effective strategies to combat heatwaves, as well as improving public safeguards, are and will continue to be pivotal challenges across the intersecting fields of climate change and public health.

In an effort to mitigate the health consequences of heat, the United States pioneered the establishment of the Hot Weather-Health Watch/Warning System during the 1990s. This was not only based on traditional high-temperature forecast warnings, but also focused on the premature mortality risk (*8*). The devastating heatwave of 2003 spurred many European countries into active research about health risks associated with such heatwaves. This resulted in the development of a more comprehensive heat health warning system (*9*). In 2015, to further global public health protection, the World Meteorological Organization and WHO collaboratively published the guidance document “Heatwaves and Health: Guidance on Warning-System Development”. This aimed to influence the development of similar early warning systems worldwide (*10*).

In China, the reaction to heatwaves primarily depends on the early heat wave warnings disseminated by the China Meteorological Administration, which consist of three classifications: yellow, orange, and red. However, this system exclusively considers temperature intensity, neglecting the correlation between heatwaves and health ramifications. Consequently, its effectiveness in safeguarding public health remains limited. Over the past two decades, Chinese researchers have endeavored to develop a more efficient heatwave health risk early warning system. Despite pieces of related research, the full-scale implementation of this system across the country has not yet materialized.

In 2001, the Shanghai Meteorological Bureau, in conjunction with the Shanghai Health Commission, launched the pioneering “Heatwave/Health Warning System” in Shanghai Municipality (*11*). Subsequently, in 2013, led by the National Institute of Environmental Health, Chinese Center for Disease Control and Prevention (NIEH, China CDC), a heatwave health early warning system was set up in Shenzhen, Nanjing, Chongqing, and Harbin, which are located in various climatic zones with different climatic characteristics (*12*–*14*). Researchers gathered historical data related to meteorology, air quality, mortality, and morbidity, and established models to identify the relationships between heatwaves and mortality and morbidity rates for various diseases in each city. The warning levels encompass red, orange, yellow, and blue. Depending on the risk reaching the corresponding warning level, the system generates an alert indicating the disease risk level, appropriate response measures, and recommendations for mitigation for diverse population groups. However, this system only operated on a trial basis and was not expanded nationwide.

In response to the prevailing global heatwaves and the inadequate public health protective measures in many countries, we recently proposed a comprehensive prevention and control framework. This framework incorporates a full spectrum coverage of heat health risk management into heat health early warning systems. It includes identifying warning signals based on the attributes of health issues caused by heat, and undertaking proactive and targeted measures on the basis of early warning information concerning heat-related health risks throughout the summer season (*15*). Under this framework, researchers from the NIEH, China CDC, developed a heat health risk early warning model that includes China's various climatic zones. The model, which relies on heat or heatwave-related mortality risks, recognizes the threshold levels for health risk surveillance, watch, and warnings (consisting of three warning levels) applicable for the entire summer season. This innovative model, which provides heat health risk alerts throughout the summer, allows for a more comprehensive public management of heat health risks compared to previous models that focused solely on warnings for extreme heat or health risks associated with extreme heat.

This innovative model has been successfully translated to local CDCs for application. For example, in collaboration with the NIEH, China CDC, the Jinan CDC leveraged this model to develop a heat health risk early warning announcement platform that issued its first cautionary message about heat or heatwave-related health risks on August 2, 2021. The platform provides a three-day forecast on potential heat or heatwave-related health risk surveillance, watch and warning information for Jinan City, which is disseminated via WeChat Official Account of the Jinan CDC. In addition to covering all local counties, the platform also provides health protection recommendations. The public can therefore access early warning information from the platform to understand their health risk from the heat or heatwaves predicted for the next three days, facilitating proactive protection against the impending high temperatures. According to the estimation, the implementation of this heatwave health risk early warning in Jinan resulted in a reduction of 10.9 deaths per million people during the 2022 warm season's warning stage. Furthermore, it helped to prevent economic losses of approximately 227 million Chinese Yuan (CNY). If this early warning system had been implemented nationally during the warm season of 2022, it could have yielded significant health benefits, potentially saving 15,115 lives and averting economic losses of approximately 62.0 billion CNY (*16*). In conclusion, the successful adoption of this system in Jinan represents a solid foundation for its further promotion among other local CDCs in China.

This edition centers on the subject of heat health risk early warning, incorporating two "Preplanned Studies" articles and one "Recollections" piece. An analysis by Chen et al. appraised the benefits of utilizing the heat health risk warning model in Jinan, and the potential for its nationwide promotion in the future (*16*). To tackle the deficiency in extended-term heatwave forecasts, Zhang et al. launched an innovative early warning system with the goal of predicting heatwave-related health hazards, within China, at sub-seasonal to seasonal intervals. The results from the evaluation indicated substantial potential for this system (*17*). Sun et al. conducted a review of NIEH, China CDC's experience in promoting environmental health risk early warning intervention, and suggested upcoming challenges and prospects (*18*). This special issue methodically encapsulates nationwide experiences of pioneering efforts in heat health risk early warning, thus providing a robust foundation for China CDC to further advance health risk early warning for environmental risk factors such as heat throughout the country.

One of the functions of the newly established National Bureau of Disease Control and Prevention is surveillance and early warning. There is an immediate need to develop early health risk warnings for environmental risk factors such as heatwaves. We propose the following steps. First, a standard technical system for early health risk warnings stemming from environmental risk factors must be designed in advance. Second, creating and publicly disseminating an information platform that can forecast and provide early warnings about health risks from environmental hazards is essential, with a focus on protecting vulnerable populations. Third, efforts should be accelerated to establish working and emergency consultation mechanisms for early health risk warnings related to heatwaves and other hazardous environmental factors. Additionally, the development of a coordinated mechanism between the national CDC and local CDCs is crucial. Finally, we recommend the gradual establishment of a collaborative working mechanism for early health risk warnings, with the China CDC serving as the primary issuer and multiple departments collaborating.

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Preplanned Studies

Evaluating the Applicability and Health Benefits of the Graded Heat Health Risk Early Warning Model — Jinan City, Shandong Province, China, 2022

Chen Chen[1,&]; Jing Liu[2,&]; Menghan Wang[1]; Liangliang Cui[3]; Tiantian Li[1,#]

Summary

What is already known about this topic?

The heat health early warning model serves as an effective strategy for reducing health risks related to heatwaves and improving population adaptability. Several high-income countries have taken the lead in conducting research and implementing measures aimed at safeguarding their populations.

What is added by this report?

The graded heat health risk early warning model (GHREWM) in Jinan City has demonstrated efficacy in safeguarding males, females, individuals aged above 75 years, and those with cardiopulmonary diseases. During the summer of 2022, the warning stage of GHREWM contributed to the prevention of 10.9 deaths per million individuals, concurrently averting health-related economic losses estimated at approximately 227 million Chinese Yuan (CNY).

What are the implications for public health practice?

The GHREWM has the potential to enhance cities' adaptability to climate change. It is crucial to incorporate additional adverse health endpoint data in the development of early warning models, as this will improve their applicability and protective efficacy.

In the summer of 2022, the world experienced unprecedented heatwaves, which broke previous records and led to severe droughts and wildfires. Due to global warming, heatwaves are expected to become more frequent and intense (*1*). Some high-income countries have implemented heat health early warning models to mitigate the impacts of heatwaves and have reported initial positive health outcomes (*2*). The World Health Organization (WHO) and the World Meteorological Organization (WMO) jointly endorsed heat health early warning models as proactive adaptation measures to reduce heat-related mortality and prevent the onset of heat-sensitive diseases during summer months (*3*). However, research on heat health early warning models in China began relatively late, and a national model has yet to be established (*2*).

In 2021, Jinan City, Shandong Province implemented a graded heat health risk early warning model (GHREWM) focused on population-health-oriented management (*4*). Further investigations are necessary to assess the utility and effectiveness of this novel heat health early warning model in safeguarding the health of residents. In the current study, an episode-based approach was employed to evaluate the applicability of Jinan's GHREWM for heat-sensitive diseases and mortality across various populations. Additionally, this study aimed to quantify the health benefits associated with the reduction of mortality risks. These findings can serve as a critical foundation for the scientific establishment of a national GHREWM in China.

In order to evaluate GHREWM's capacity to identify health risks, daily mortality data from 8 urban areas in Jinan City, Shandong Province, China, during the warm seasons (May to October) between 2013 and 2018 were collected utilizing the Disease Surveillance Point System of the China CDC. Three categories of mortality causes were considered: non-accidental, circulatory diseases, and respiratory diseases, further stratified by age (<65 years, 65–74 years, and >74 years) and gender (female and male). Daily 24-hour average temperature, relative humidity, and ozone (O_3) concentrations were obtained from the National Climate Centre, the European Centre for Medium-range Weather Forecasts, and the National Urban Air Quality Real-time Release Platform, respectively.

In calculating health benefits, we gathered data from the GHREWM, including daily 24-hour average temperatures for the 2022 warm season, number of resident populations, and gross domestic product (GDP)-adjusted provincial value of a statistical life (VSL). The GHREWM, organized by heatwave mortality risks, encompasses surveillance, watch, and warning stages. The warning stage consists of warning levels 1, 2, and 3 (Supplementary Figure S1, available in https://weekly.chinacdc.cn). The GHREWM's structure and warning grading thresholds for different climate-architecture regions are depicted in Supplementary Figure S1 and Supplementary Table S1 (available in https://weekly.chinacdc.cn). Additional information regarding the sources and contents of the data can be found in the Supplementary Materials (available in https://weekly.chinacdc.cn).

This study utilized an episode-based approach and a two-stage statistical model to examine associations between warning levels and daily mortality risks for three sensitive diseases and sub-populations, determining if mortality risks varied with increasing warning levels. In the first stage, a generalized linear model employing quasi-Poisson regression was applied to fit county-specific associations, adjusting for relative humidity, time trends, and days of the week. In the second stage, a random-effects meta-analysis was conducted to pool the associations. The settings for the primary model and sensitivity analysis can be found in Supplementary Materials. Associations were expressed as percentage increases in mortality associated with a one-rank increase in warning levels, using the surveillance stage as the reference level.

We calculated the number of deaths prevented per million individuals and the economic losses averted during the warm season of 2022, as a result of the warning stage, in order to assess the health benefits provided by GHREWM in Jinan (*5*–*6*).

$$\Delta Lives = \sum(\Delta Mortality \times days_i \times pop_i)$$

$$VSL_{total} = \sum(\Delta Mortality \times days_i \times pop_i \times VSL_i)$$

In this formula, $\Delta Lives$ and VSL_{total} represent the number of lives saved and the economic loss avoided by the warning stage, respectively. $\Delta Mortality$ [0.69 persons/(million people·day)] refers to the number of deaths prevented per million people per day and is derived from the estimated number of deaths per million population per day saved by the warning stage in Benmarhnia's study, as described in detail in Supplementary Materials and adjusted for population size (*5*). $days_i$ represents the number of days in the warning stage for area i; pop_i denotes the local population for area i; and VSL_i is the VSL at the provincial level for area i (*6*).

Assuming the nationwide implementation of the GHREWM model in 2022, health benefits were estimated for six climatic-architecture regions (covering 366 cities), utilizing the number of lives saved and adjusting for the local population in Jinan.

The R Statistical software (version 4.0.2; Kurt Hornik and the R Core Team, Vienna, Austria) was used to perform all analyses. Statistical significance was set at $P<0.05$. ArcGIS (version 10.7; Esri Inc., RedLands, California, USA) was used to draw the map of China.

Between 2013 and 2018, during the warm seasons, a total of 104,346 non-accidental disease-related deaths were reported in Jinan. Of these, 55.8% were males, and 44.2% were females. The majority of the deceased were aged 75 years and older (Table 1).

As illustrated in Figure 1, the watch level demonstrated a substantial rise in the risk of non-accidental and circulatory disease-related deaths in comparison with the surveillance stage. This increase amounted to 8.20% [95% confidence interval (*CI*): 5.37%, 11.11%] and 9.34% (95% *CI*: 5.43%, 13.40%), respectively. During the warning stage, the augmentation in mortality risks associated with non-accidental, circulatory, and respiratory diseases in the general population correlated with an escalation in the warning level. The most significant increase was observed at warning level 3, with risks of 31.81% (95% *CI*: 17.41%, 47.97%), 39.94% (95% *CI*: 19.12%, 64.41%), and 49.24% (95% *CI*: 22.03%, 82.51%), respectively. These findings suggest that the GHREWM model possesses a robust capacity for identifying health risks based on their ranking.

There was a positive correlation between the increasing mortality risks and warning levels observed for both sexes and individuals aged over 75 years (Figure 1 and Supplementary Table S3 available in https://weekly.chinacdc.cn). However, this trend was not observed in the other two age groups.

Following the implementation of GHREWM in Jinan during the warm seasons of 2022, the warning stage resulted in a reduction of 10.9 deaths per million individuals and averted economic losses of approximately 227 million CNY. If applied on a nationwide scale, this strategy could have led to significant health benefits, with a potential savings of 15,115 deaths and a prevention of economic losses amounting to 62.0 billion CNY.

DISCUSSION

Jinan's GHREWM utilizes population mortality risk as a foundation for establishing warning ranks and adopts the three-stage risk management concept of risk surveillance, watch, and warning to address heat-related health risks during summer (*4*). Existing heat

TABLE 1. Overview of daily mortality causes, meteorological factors, and ozone (O_3) levels in Jinan City, Shandong Province during warm seasons (May–October) from 2013 to 2018.

Variable	Total	Mean±SD	P_{50} (P_{25}, P_{75})
Cause of Mortality			
Non-accidental disease	104,346	12±6	11 (7, 15)
Female	46,130	5±3	5 (3, 7)
Male	58,212	7±4	6 (4, 9)
Age <65 years	26,877	3±2	3 (1, 4)
Age 65–74 years	22,377	3±2	2 (1, 4)
Age >74 years	55,082	6±4	6 (4, 8)
Circulatory disease	54,809	6±4	6 (4, 8)
Respiratory disease	8,864	1±1	1 (0, 2)
Environmental Factors			
Temperature (°C)		22.7±5.1	23.6 (19.7, 26.5)
Relative humidity (%)		66.2±14.6	67.4 (55.7, 77.4)
O_3 8 h-average (μg/m^3)		133.5±58.8	135.9 (91.1, 175.8)

Note: Mean represents the daily average of a variable during the warm seasons from 2013 to 2018.
Abbreviation: SD=standard deviation; P_{25}=the 25th percentile; P_{50}=the 50th percentile; P_{75}=the 75th percentile.

health early warning models in high-income countries, such as the United Kingdom and France, primarily focus on identifying heatwaves associated with elevated health risks (*2*). In contrast, Jinan's GHREWM refines the classification of early warning levels, which our findings suggest effectively represents the increasing tendency of heat health risks, particularly for individuals over 75 years of age and those with cardiopulmonary diseases.

This study demonstrates that early warning grading based on mortality risk is more sensitive to populations with death as the primary effect endpoint (e.g., adults over 65 years of age). However, it also indicates that constructing a health early warning model solely based on death data may not capture the full range of heat-related effects on all populations. For instance, children tend to spend more time outdoors, exposing themselves to higher temperatures for extended periods, and their limited self-protection abilities (*7*) increase their susceptibility to high-temperature-induced diseases, such as heat stroke. Consequently, future heat health warning research should consider incorporating various sensitive effect endpoints.

The United Nations Intergovernmental Panel on Climate Change's Sixth Assessment Report highlights the positive effects of 24 representative adaptation measures on human well-being, with the benefits of disaster early warning systems on human health being particularly notable (*8*). Successful implementations in high-income countries have shown significant health benefits from population-based risk approaches for early disaster warnings. Benmarhnia et al. estimated that heat action plans in Montreal, Quebec, reduced mortality by 2.52 deaths per day during heatwaves (*5*). Additionally, the nationwide heatwave plan for England saved 1,189 lives over a 20-day heatwave in 2013 (*9*). Philadelphia's Hot Weather-Health Watch/Early Warning System resulted in 117 lives saved between 1995 and 1998, generating 468 million USD in revenue (*10*). Our study also illustrates the benefits of implementing Jinan's GHREWM in the summer of 2022. As the negative effects of climate change are irreversible, effective adaptation measures (such as GHREWM) provide a practical and timely means of preventing further losses.

Rapid urbanization has led to increased population density, which, when combined with the urban heat island effect and severe air pollution, negatively impacts urban living conditions. Addressing the growing health needs of the population and enhancing urban resilience and adaptability to climate change have become critical challenges. Our study indicates that implementing the Jinan's health warning model nationwide in 2022 could have yielded significant health benefits for residents. Consequently, we recommend the immediate establishment of a national heat health early warning system to better adapt to the escalating trend of extreme heat events, accompanied by the execution of a multi-sectoral heat health collaboration action plan.

This study was subject to several limitations. First, due to the inability to accurately measure personal

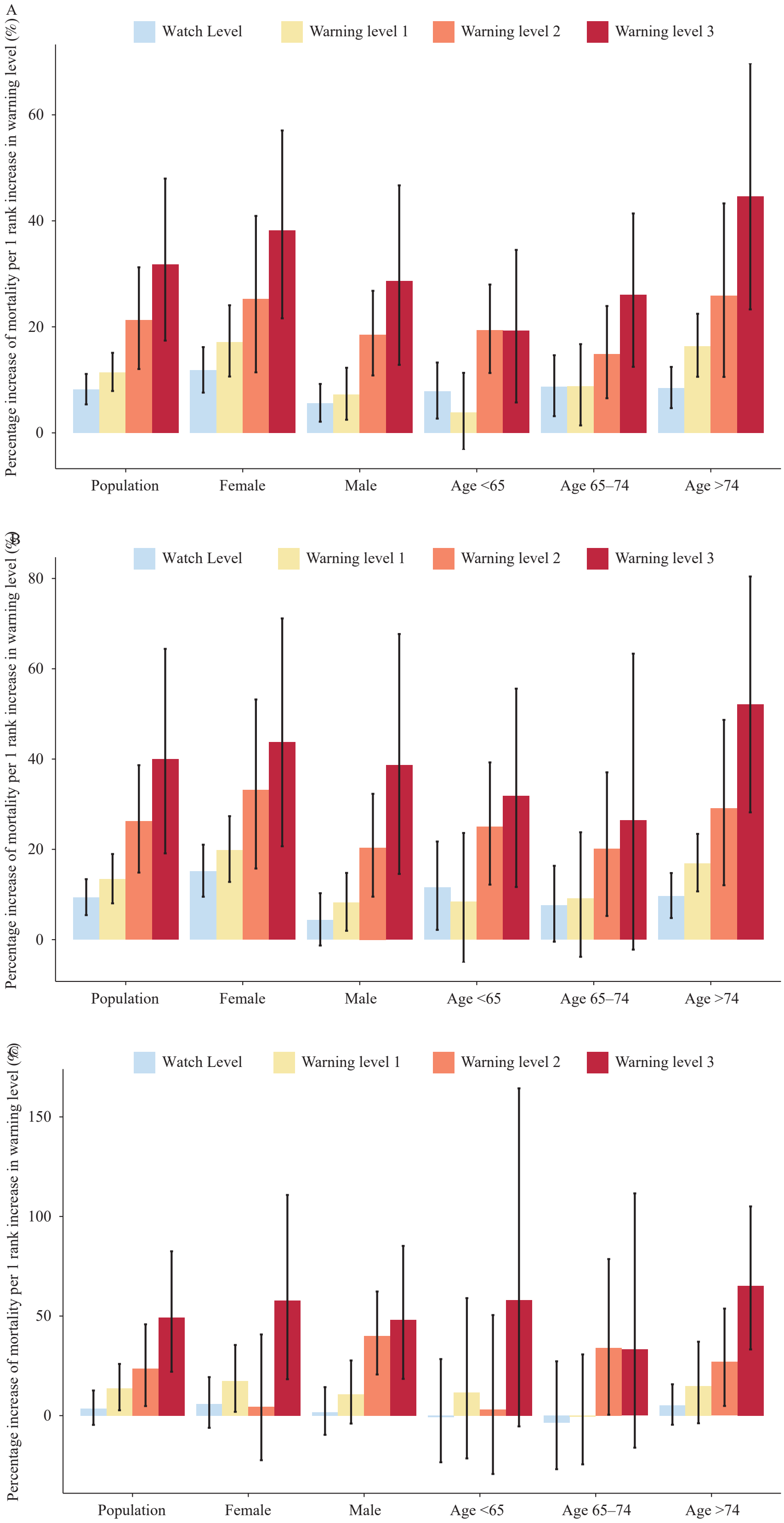

FIGURE 1. Percentage increase in non-accidental mortality (A), circulatory mortality (B), and respiratory mortality (C) per 1 rank increase in warning level during warm seasons in Jinan from 2013 to 2018, with population and sub-population estimates displayed.

temperature exposure, we utilized ambient temperature as a proxy for individual exposure, potentially introducing exposure uncertainty. Second, the assessment of national health benefits relied on scenario assumptions, serving as a reference for the nationwide value derived from the application of GHREWM. Furthermore, the establishment of GHREWM did not encompass certain western regions; hence, these areas were excluded from the estimation of nationwide health benefits.

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SUPPLEMENTARY MATERIAL

Methods

Data: To evaluate the capability of graded heat health risk early warning model (GHREWM) in identifying health risks, daily mortality data for eight urban areas in Jinan City, China, during the warm seasons (May to October) from 2013 to 2018 were collected from the Disease Surveillance Point System of China CDC. Three categories of death causes were classified based on the 10th Revision of the International Statistical Classification of Diseases, which included: non-accidental diseases (A00-R99), circulatory diseases (I00–I99), and respiratory diseases (J00–J99). These categories were further divided by age groups (<65, 65–74, and >74 years) and gender (female and male). Daily 24-hour average temperature, relative humidity, and O_3 concentrations data were acquired from the National Climate Centre (www.ncc-cma.net), the European Centre for Medium-range Weather Forecasts (https://cds.climate.copernicus.eu/), and the National Urban Air Quality Real-time Release Platform (http://www.cnemc.cn), respectively.

In the assessment of health benefits, the GHREWM information, the number of resident populations, and the GDP-adjusted provincial VSL were gathered from various sources. These included the Jinan CDC, the China Meteorological Administration (https://weather.cma.cn), the Seventh National Population Census of China in 2020, and Sun's study (*1*).

The structure of the GHREWM: The GHREWM was developed using historical mortality monitoring data to conduct a time-series study. This study aimed to quantify the characteristics of the mortality risk curve by constructing the exposure-response relationship between temperature and non-accidental death in various climate regions and subsequently categorizing the warning levels. The GHREWM comprises surveillance, watch, and warning stages, with the warning stage including levels 1, 2, and 3 (Supplementary Figure S1).

During the surveillance stage, heat health risks are consistently monitored throughout the summer season. At the watch stage, health risks are relatively low, indicating that authorities should prepare for potential heatwaves. As the warning stage commences, health risks increase, becoming more significant as the warning level escalates. In response to this heightened risk, authorities must provide health guidance and implement protective measures based on the current warning level.

The structure of the GHREWM and the warning thresholds for different climatic-architecture regions can be found in the Chinese Environmental Public Health Tracking project conducted by China CDC (Supplementary Figure S1 and Supplementary Table S1) (*2*). In accordance with the climate patterns in Jinan, the warning grading thresholds were determined using the 91st, 95th, 98th, and 99.5th percentiles of daily 24-hour average temperatures recorded from 2013 to 2018.

<table>
<tr><th colspan="2">Early warning stages</th><th>Early warning signals</th><th>Heat health risk grading information</th><th>Heat health risk grading basis</th></tr>
<tr><td colspan="2">Health risk surveillance</td><td>Green</td><td>heat health risks are lower</td><td>/</td></tr>
<tr><td colspan="2">Health risk watch</td><td>Blue</td><td>there are certain heat health risks</td><td>The temperature threshold is the 91–92th percentile of historical daily mean temperature, and the daily mean temperature exceeds the threshold within 24-h.</td></tr>
<tr><td rowspan="3">Health risk early warning</td><td>Level 1</td><td>Yellow</td><td>heat health risks are high</td><td>The temperature threshold is the 95–97th percentile of historical daily mean temperature, and the daily mean temperature exceeds the threshold for two consecutive days.</td></tr>
<tr><td>Level 2</td><td>Orange</td><td>heat health risks are higher</td><td>The temperature threshold is the 97–98th percentile of historical daily mean temperature, and the daily mean temperature exceeds the threshold within 24-h.</td></tr>
<tr><td>Level 3</td><td>Red</td><td>heat health risks are extremely high</td><td>The temperature threshold is the 99.5th percentile of historical daily mean temperature, and the daily mean temperature exceeds the threshold within 24-h.</td></tr>
</table>

SUPPLEMENTARY FIGURE S1. Structure of the graded heat health risk early warning model (GHREWM).

Statistical Analyses

Main model: $Log[E(Y_t)] = \alpha + \beta warning\ level_t + ns(time, df) + RH + dow$

where $E(Y_t)$ is the expected number of mortality on day t; β represents the associations between warning levels and mortality; $warning\ level_t$, a dummy variable of 0, 1, 2, 3 or 4, represents the warning level on day t;$warning\ level_t$ = 0 if day t is surveillance stage, 1 if day t is watch level, 2 if day t is warning level 1, 3 if day t is warning level 2, and 4 if day t is warning level 3; RH is relative humidity; and $ns(time, df)$ is the natural spline functions of time trends with 2 degrees of freedom (df) per year. dow is a dummy variable for the day of the week.

Sensitivity analysis: We performed three sensitivity analyses for non-accidental mortality, as demonstrated by 1) the specification of df in the natural spline of the time trend (df_{time}=3/year) to investigate the effect of df adjustment changes on model estimates; 2) controlling relative humidity using a natural spline with 2 df to assess model stability; and 3) adjusting for ozone (O_3) in the analysis to evaluate the influence of air pollutants on model estimates. Results from the sensitivity analyses indicated that our findings were relatively robust (Supplementary Table S2).

Health benefits: $\Delta Mortality = \Delta Deaths/pop \times 1\ million$

SUPPLEMENTARY TABLE S1. Relative thresholds for each warning level in different climatic-architecture regions.

Region	Watch level	Warning level		
		Warning level 1	Warning level 2	Warning level 3
Severe cold region	91.0	95.0	98.0	99.5
Cold region	91.0	95.0	98.0	99.5
Hot summer & cold winter region	91.0	96.0	98.0	99.5
Temperate region	92.0	95.0	97.0	99.5
Hot summer & warm winter region	92.0	96.0	98.0	99.5
Severe cold & cold (northwestern) region	91.0	97.0	98.0	99.5

SUPPLEMENTARY TABLE S2. Percentage increase (95% *CI*) in non-accidental mortality associated with a per 1 level increase in warning level for sensitivity analysis via model setting adjustments.

Warning level	Main model		df_{time}=3/year		Controlling relative humidity by nature spline		Adjusting O_3	
	PI (95% *CI*)	QAIC	PI (95% *CI*)	QAIC	PI (95% *CI*)	QAIC	PI (95% *CI*)	QAIC
Watch level	8.20 (5.37, 11.11)	3.90	8.43 (5.52, 11.42)	5.28	8.19 (5.36, 11.10)	3.98	7.69 (4.70, 10.75)	4.17
Warning level 1	11.44 (7.90, 15.10)	6.28	11.45 (7.86, 15.17)	5.55	11.39 (7.85, 15.05)	6.38	11.71 (7.63, 15.95)	8.24
Warning level 2	21.26 (12.05, 31.24)	30.41	21.35 (12.67, 30.71)	27.08	21.04 (11.69, 31.16)	31.23	20.28 (12.15, 29.01)	21.83
Warning level 3	31.81 (17.41, 47.97)	26.97	31.17 (16.89, 47.20)	27.02	31.36 (16.86, 47.67)	27.59	31.82 (17.49, 47.90)	25.53

Note: df_{time} refers to the natural spline of the df for the time trend.
Abbreviation: PI=percentage increase; *CI*=confidence interval.

SUPPLEMENTARY TABLE S3. Percentage Increase (95% *CI*) in mortality associated with a per 1 level increase.

Cause of Mortality	Watch level	Warning level		
		Warning level 1	Warning level 2	Warning level 3
Non-accidental disease	8.20 (5.37, 11.11)	11.44 (7.90, 15.10)	21.26 (12.05, 31.24)	31.81 (17.41, 47.97)
Female	11.80 (7.59, 16.18)	17.16 (10.63, 24.07)	25.31 (11.42, 40.93)	38.20 (21.61, 57.05)
Male	5.61 (2.11, 9.23)	7.27 (2.48, 12.28)	18.55 (10.83, 26.80)	28.65 (12.83, 46.69)
Age <65 years	7.85 (2.69, 13.27)	3.85 (−3.12, 11.32)	19.35 (11.30, 27.98)	19.26 (5.73, 34.52)
Age 65–74 years	8.74 (3.15, 14.64)	8.80 (1.40, 16.74)	14.90 (6.53, 23.93)	26.10 (12.46, 41.39)
Age >74 years	8.48 (4.67, 12.44)	16.37 (10.58, 22.47)	25.86 (10.56, 43.29)	44.62 (23.29, 69.64)
Circulatory disease	9.34 (5.43, 13.40)	13.37 (8.04, 18.97)	26.19 (14.85, 38.64)	39.94 (19.12, 64.41)
Respiratory disease	3.63 (-4.64, 12.62)	13.73 (2.69, 25.95)	23.63 (4.80, 45.85)	49.24 (22.03, 82.51)

Where $\Delta Mortality$, 0.69 persons/(million people·day), is the cases saved per million people per day; $\Delta Deaths$ is the daily mortality reduced by the heat action plan in Montreal, 2.52 deaths (*3*); *pop* is the population in Montreal, 3.64 million, from 2006 Census of Canada.

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Preplanned Studies

An Early Warning System for Heatwave-Induced Health Risks in China: A Sub-Seasonal to Seasonal Perspective — China, 2022

Baichao Zhang[1]; Huiqi Chen[2]; Bo Lu[1,#]

Summary

What is already known about this topic?

Climate change has had a detrimental impact on global health, particularly through the rise of extreme heatwaves. Presently, the early warning system for heatwave-related health risks can forecast potential dangers several days in advance; however, long-term warnings fall short.

What is added by this report?

This report introduces a novel early warning system aimed at predicting heatwave-induced health risks in China at sub-seasonal to seasonal timescales. The outcomes of the assessment suggest this system holds significant potential.

What are the implications for public health practices?

The system facilitates advanced assessment of both the scale and dispersal of risk among various demographic groups. This allows for the proactive management of potential risks with extended lead times.

Global climate change has had a negative impact on the physical health of populations worldwide, with heatwave events causing significant human mortality and morbidity (*1*). The formation of an early warning system for health risks induced by heatwaves is vital, as it facilitates proactive measures by public health practitioners and public individuals. Current methodologies have developed various systems that provide advance warning several days ahead, effectively lessening heat-related dangers (*2*–*6*). The adoption of long-term pre-warning measures aids in preparing individuals and policymakers to take informed actions to reduce potential risks.

Despite the initial success of these long-term heatwave predictions, there remains a notable deficit in the provision of a health-risk warning system that covers the sub-seasonal to the seasonal scales (spanning two weeks to two months). The aim of this paper is to present a system that successfully addresses this gap.

By incorporating the China heatwave-attributable mortality model (*7*–*8*) with real-time temperature forecasts from the China Meteorological Administration-Climate Prediction System (CMA-CPSv3), this system provides up-to-date estimates of mortality rates and burdens for the forthcoming two months. As such, this system is poised to serve as a valuable tool for public health practitioners, enabling them to better plan personnel deployments and effectively allocate resources.

This study aims to combine heatwave events and health-risk assessment tools by using real-time, rolling temperature data projected for the subsequent 60 days from the advanced CMA-CPSv3 prediction system. Notably, the CMA-CPSv3 applies the enhanced resolution version of the Beijing Climate Center Climate System Model (BCC-CSM2-HR), recognized for its accuracy in predicting high temperatures within China (*9*). Initially, we commenced by systematically rectifying the temperature components produced by the CMA-CPSv3. A series of at least 3 days during the summer months (May to September) when the daily peak temperature surpasses the 92.5th percentile of the reference period (1961–2020) is characterized as a heatwave.

We utilized the nationwide heatwave-attributable mortality model established by Chen et al. (*7*–*8*) to analyze the health risks associated with heatwaves, including related mortality burden and death rate. This model investigates the specific exposure-response functional relationships between heatwaves and ensuing deaths across different climate zones using generalized linear models and meta-analysis. Estimations of mortality burden ascribed to heatwaves employ risk appraisals applicable to respective gridded heatwave series and nationwide mortality. The model considers factors such as population size, mortality rate, heatwave frequency, and exposure-response dynamics. By integrating the computed heatwave day data into the model, we ascertained the death burden and death rate due to heatwave-induced fatalities (depicted as gridded mortality burden per million population). A representation of this approach is illustrated in Figure 1.

Table 1, issued on July 1, 2022, provides estimates for the number of heatwave days expected in China over the subsequent two months. Data indicate a higher projection of heatwave days for July in regions like Western Sichuan, Chongqing, and other areas of Central China, with more than 20 heatwave days predicted per month. Similarly, nearly 20 days of heatwave occurrences were estimated for Northwest China, inclusive of areas such as Ningxia and Xinjiang. Moving into August, the northern reaches of Northeast

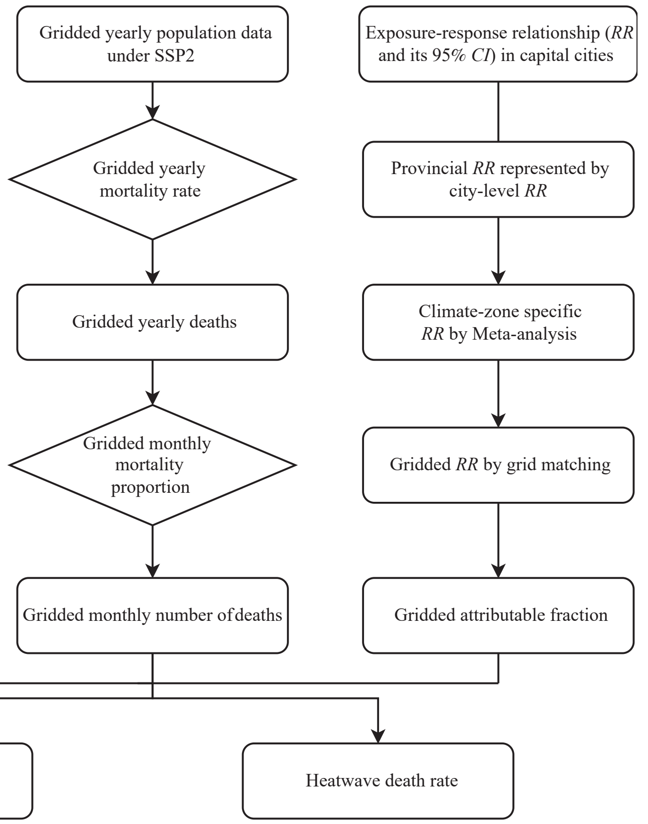

FIGURE 1. Flow diagram illustrating the operational process of the early warning system.
Abbreviation: RCMs=regional climate models; RCP=representative concentration pathways; SSP=shared socio-economic pathway; CMIP=coupled model intercomparison project; *RR*=relative risk; AF=attributable fraction; DMT=daily maximum temperature.

TABLE 1. Top 10 provincial-level administrative divisions (PLADs) by number of heatwave days, resulting death burden, and death rate.

Heatwave days				Heatwave-induced death burden				Heatwave-induced death rate			
0–30 days		31–60 days		0–30 days		31–60 days		0–30 days		31–60 days	
PLAD	Value	PLAD	Value	PLAD	Value	PLAD	Value	PLAD	Value	PLAD	Value
Chongqing	20.63	Anhui	20.01	Henan	3,530	Henan	3,402	Xinjiang	17,318	Xinjiang	21,003
Ningxia	19.25	Xinjiang	19.72	Shaanxi	1,817	Sichuan	1,750	Inner Mongolia	9,119	Inner Mongolia	12,471
Shaanxi	19.10	Chongqing	16.26	Sichuan	1,809	Anhui	1,666	Gansu	6,498	Gansu	4,418
Gansu	18.48	Hebei	15.61	Hubei	1,498	Hubei	1,663	Qinghai	4,588	Heilongjiang	4,060
Qinghai	18.44	Henan	14.79	Shandong	1,050	Jiangsu	1,331	Shaanxi	3,682	Henan	2,412
Hebei	18.00	Guizhou	14.76	Gansu	959	Shandong	1,316	Xizang	3,199	Qinghai	2,335
Xinjiang	17.00	Hunan	12.94	Anhui	941	Shaanxi	893	Sichuan	2,851	Sichuan	2,113
Sichuan	15.63	Inner Mongolia	12.85	Shanxi	736	Xinjiang	804	Henan	2,571	Hubei	1,837
Henan	15.45	Jiangsu	12.30	Xinjiang	608	Inner Mongolia	642	Heilongjiang	2,268	Shaanxi	1,751
Anhui	12.14	Gansu	12.09	Inner Mongolia	525	Heilongjiang	603	Hubei	2,085	Anhui	1,452

China forecast an increased frequency of heatwave days, with most regions predicted to experience over 20 such days per month on average. Of particular note is the Yangtze River Basin, which endured the most intense heatwave event ever recorded in the late summer of 2022 (*10*). As outlined in Table 1, this model accurately predicted this distinct pattern a month in advance.

The projected results were released on July 1, supplemented by real-time daily forecasts for one-month duration heatwave days in the summer of 2022. Figure 2 compares estimated and actual data, with solid lines reflecting observed data and dashed lines illustrating CMA-CPSv3 predictions. The figure demonstrates CMA-CPSv3's effective prediction of heatwave events during the summer of 2022. Accurate forecasting of heatwave days forms the basis for dependable subsequent estimations of heatwave health risks.

The study provided an analysis of the mortality rate due to heatwaves in July and August 2022, as depicted in Table 1. When contrasted with heatwave occurrences, the distribution of heatwave-related mortality correlates strongly with heatwave patterns in central China. Henan and Sichuan, both populous provinces, recorded the highest mortality rates due to heatwaves, with approximately 3,400 and 2,000 deaths respectively. Upon conducting a subgroup analysis, cardiovascular diseases (CVD) emerged as the leading cause of heatwave-induced mortality, contributing to an estimated 80% of the cases. Further, seniors and females were found to be at a relatively higher risk, accounting for around 75% and 70% of cases respectively.

The mortality burden indicator can enable policymakers and public health practitioners to allocate resources effectively. Nonetheless, it is crucial to acknowledge that the impact of the mortality burden during heatwaves is related to the local population size, which may limit its relevance on an individual basis. Therefore, this indicator also includes a heatwave-related mortality rate, derived from the mortality burden per million people during heatwaves. Over a span of two months, the highest risk was observed in Xinjiang, with an estimated heatwave-related mortality risk of about 20,000 per million individuals monthly. This was closely followed by Inner Mongolia, which had a risk estimated at 10,000 individuals per million monthly. Notably, the risk in August surpassed that of July.

DISCUSSION

This study presents two results within the sub-seasonal to a seasonal early warning system for heatwave-related health risks: death burden and death rate. These results can be beneficial for a variety of users. For policymakers and public healthcare practitioners, the distribution of heatwave incidents and a ranking system for province-wide mortality burden due to heatwaves can help inform the scope of heatwave impacts, prioritize critical areas, and effectively allocate resources. For individual users, the mortality rate due to heatwaves gives a more precise understanding of an individual's risk during a heatwave event, assisting in making well-informed travel plans and activity scheduling.

The two outputs show variations in detail when compared with the prediction of heatwave days. For instance, while the northeastern and northwestern regions of China experience more heatwave days, they

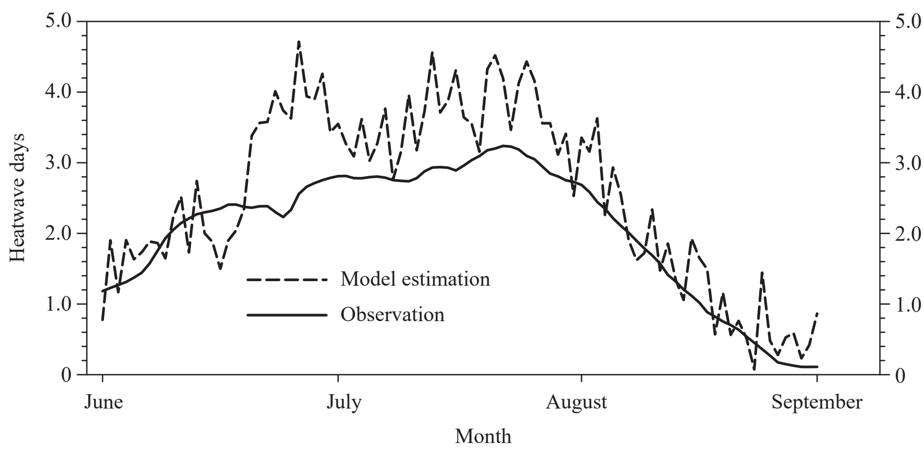

FIGURE 2. Comparison of the average heatwave days predicted over the next 30 days in China (dashed curve) with actual observations (solid curve).

show a lower heatwave-induced mortality burden due to their lower population densities. The heatwave-induced mortality rate provides a more accurate representation of the effect of heatwave duration on individuals. As expected, higher heatwave mortality rates align with the predicted heatwave days in the northeastern and northwestern regions. However, despite the high number of heatwave days in Sichuan-Chongqing, there is no significant increase in heatwave-induced mortality rate. This is likely due to the region's higher adaptive capacity to high temperatures, as its population has been exposed to such conditions for a long period of time. Consequently, despite experiencing the same number of heatwave days as in other regions, the risk in Sichuan-Chongqing is lower than in the northeastern and northwestern regions of China.

This study possesses numerous limitations. Predominantly, the CMA-CPSv3 data estimation appeared to slightly exaggerate the quantity of heatwave days in July. Further, the all-encompassing model for heatwave-related mortality utilized in this study does not accommodate prospective shifts in population exposure and vulnerability. Additionally, the hypothesized burden of heatwave deaths lacks substantiation through real-time mortality data. To address these limitations, the following remedies are suggested. 1) The improvement of climate model predictive capabilities is imperative. The enhancements presented with the development of the BCC-CSM2-HR model will allow for greater accuracy in the data derived from CMA-CPSv3. 2) The usage of multi-year estimation results for adjustments is advocated. The CMA-CPSv3 system, applied in this study, underwent certain modifications. Nonetheless, its efficacy is limited during months of extremely high temperatures due to the inadequate representation of such extreme conditions in the correction dataset. However, the performance of the modification is projected to improve as more estimated data from CMA-CPSv3 becomes available. 3) It is crucial to frequently update the nationwide model of mortality attributable to regional heatwaves to accurately depict the changing exposure and vulnerability of the population. 4) The enhancement of cross-disciplinary collaboration is of the utmost importance. This includes promoting a closer cooperation with the China CDC for the exchange of real-time mortality data and the validation of the system's outputs. Such collaboration will significantly contribute to the improvement of the system's performance.

In conclusion, the early warning system for health risks induced by sub-seasonal to seasonal heatwaves offers timely and quantitative assessments of both the impact magnitude and risk levels linked to heatwaves in China. This tool accommodates a broad spectrum of users and delivers crucial insights.

Conflicts of interest: No conflicts of interest.

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Recollections

Early Warning Interventions for Environmental Risk Factors at China CDC

Qinghua Sun[1]; Chen Chen[1]; Qing Wang[1]; Tiantian Li[1,#]

BACKGROUND

President Xi Jinping emphasized the paramount importance of bolstering early surveillance and early warning capacities within a robust public health system (*1*). These elements constitute one of the five major functionalities of the National Bureau of Disease Control and Prevention (*2*). As an integral division of the National Bureau of Disease Control and Prevention, the Center for Disease Control and Prevention (CDC) is responsible for executing early surveillance and warning procedures in the realm of public health. Nonetheless, a deficiency persists concerning the early warning of public health risk factors.

In 2019, the National Bureau of Disease Control and Prevention initiated nationwide pilots for environmental health risk assessment. Building upon these pilot studies, the National Institute of Environmental Health (NIEH) of China CDC embarked on research and development for early warning technology in environmental health risk. Utilizing factors such as air quality, heatwave, and cold-spell health risks as key areas of intervention, the NIEH undertook extensive research and development of suitable adaptive technologies. This was done through a systematic coordination of resources among all stakeholders, and exploration of effective mechanisms for health risk early warning interventions in public health.

The NIEH has successfully integrated public health considerations into early warning systems for environmental risk factors, developing intricate, health risk-based warning and intervention technologies. These encompass air quality, heatwaves, and cold spell-related health risk warnings. Building on this achievement, the NIEH has fervently promoted the early warning intervention through a pilot program on three fundamental aspects: technology research and development, platform construction, and mechanism development. Table 1 outlines the pilot program for health risk early warning initiatives related to air quality, heatwaves, and cold spells.

In recognizing the significance of integrating early warning technology into health services, the NIEH facilitated early risk intervention strategies. This resulted in the pioneering fusion of medical and disease prevention sectors, giving birth to an innovative model for preventative disease control through early health warnings. Moreover, these developments offer a distinctively Chinese solution to global practices of early warning intervention.

WORK CONTENT

NIEH conducted the following tasks.

Technology research and development: In our investigation of the primary environmental risk factors and their associated health risks in China, we focused on air pollution, heatwaves, and cold spells. We developed an early warning intervention system for health risks, grounded on localized data, parameters, and unique innovative technology (*3*–*5*). This system aims to forecast health-risk interventions within the next 3–7 days.

The construction of the platform: Building upon the comprehensive environmental health monitoring program by NIEH, we developed a health risk early warning platform for environmental risk factors. This

TABLE 1. Early warning pilots for environmental health risks.

Environmental risk factors	Pilots of early warning
Air quality	Hebei Province, Jiangsu Province, Shandong Province, Henan Province, Sichuan Province, Jinan City, Qingdao City, Ningbo City, Shenzhen City, Hefei City
Heatwaves	Jinan City, Shenzhen City, Qingdao City
Cold spells	Jinan City, Qingdao City

platform is designed to access real-time and predictive data on environmental factor exposure, automatically cleanse and compute the data, match it with health information, and share it with local CDCs for dissemination via a data interface. Figure 1 presents the architecture diagram for the data processing of this early warning system platform. A massive amount of professional real-time and forecasted environmental factor data is processed within the computing platform. This data is then cleansed, aligned and integrated in real time, following which it is paired with the graded warning model. The model is utilized to automatically compute the warning level and associate it with health recommendations. Ultimately, it produces a graded warning index that is readily comprehensible to the general public.

Mechanism development: Since 2019, in cooperation with local CDCs, a pilot program was implemented for demonstrating the application of early warning public health services. The method of data sharing between NIEH and the pilot programs is depicted in Figure 2. NIEH is tasked with the computation of the warning index, which is subsequently relayed to the local CDCs via an interface program. The local CDCs then access the data and disseminate it through their respective visualization platforms. Through this initiative, a synergistic working mechanism for early warning dissemination between national and local CDCs was gradually developed, thus advancing the technical approach to convert scientific research findings into public health services.

ACCOMPLISHMENTS AND EXPERIENCES

Development of an Early Warning Technology for Environmental Health Risks in China

Reflecting on the unique aspects of local environmental pollution in China, we developed methods for warning of health risks associated with air quality, heatwaves, and cold spells. In formulating

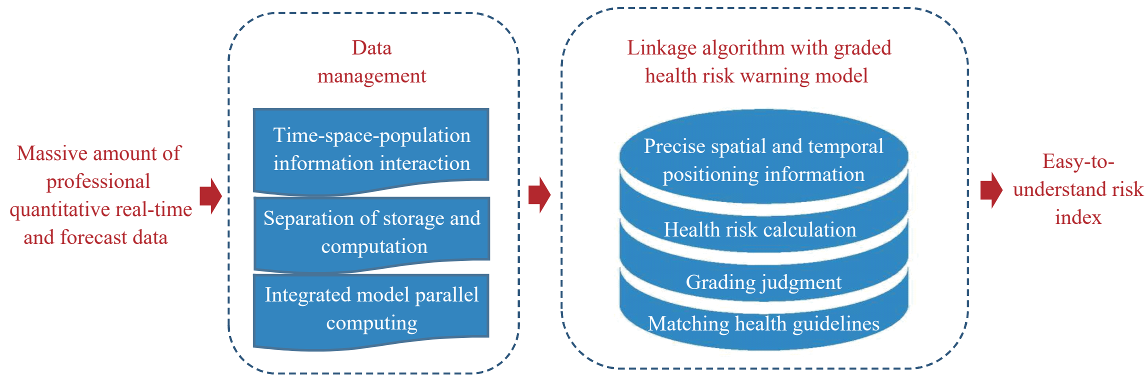

FIGURE 1. Diagram illustrating the data processing architecture of the early warning system platform.

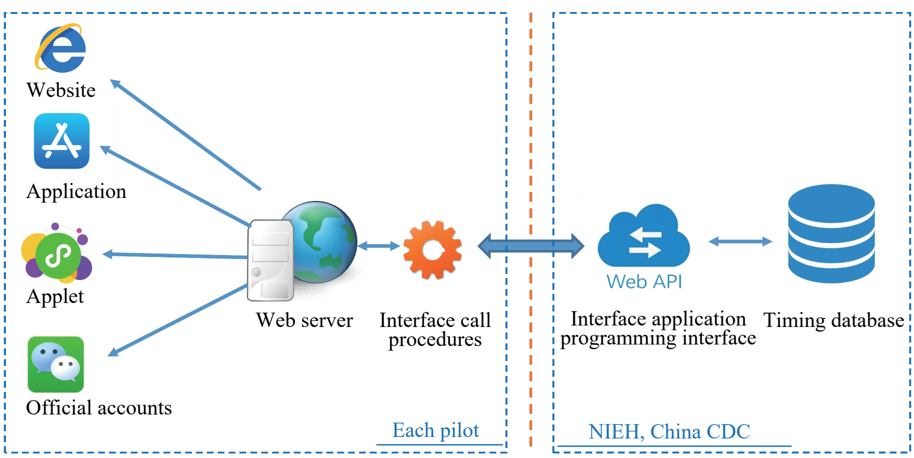

FIGURE 2. Method of data sharing between China CDC and pilot studies.

these approaches, we incorporated considerations of China's varied geographical and climatic characteristics and the adaptability of the populace among other factors. Also, a comprehensive evaluation procedure for warning validation was established, which incorporated the capability of the warning methods to highlight health risks, their synergy with the preexisting warning methods in China, and public acceptability.

Developing a Novel Public Health Service Model for Environmental Risk Factors and Health Risk Alerting

Supported public health services within the CDC: We initiated a pilot program for environmental health risk assessment in ten local CDCs. This program included the regular release of early warning intervention information. To date, the AQHI(air quality health index) has been consistently released in real-time and forecasted for over three years across two provinces and ten cities. This coverage spans a population of approximately 180 million individuals. Additionally, a health risk early warning system for heatwaves has been successfully operational in Jinan for a period of two years. Furthermore, we have implemented health risk early warning systems for cold spells in two cities.

Supported public health services in the meteorological sector: Our approach integrated health factors into the forecasting of extreme weather events through collaboration with other governmental departments. An example of this is our technical support to the Public Meteorological Service Center of the China Meteorological Administration during national extreme weather forecast gatherings. This allowed the inclusion of public health factors into predictions and warnings.

Supported public health services in medical institutions: Supported public health services in medical institutions played crucial roles in providing early warning intervention services for susceptible populations. For example, in partnership with the Chinese Cardiovascular Association, a health-risk warning linked to cold spells was disseminated to over 1,000 hospitals across the country. This notice, targeting vulnerable cardiovascular populations, provided health guidelines ahead of extreme weather events. This novel approach to risk prevention and management for individuals with high cardiovascular risk has shifted the health protection paradigm forward. Thus, it encourages the integration and synchronization of medical prevention.

Rationalizing the Collaborative Mechanism for Health Risk Warnings Related to Environmental Risk Factors

Construction of a national-provincial-municipal CDC joint working mechanism: The China CDC, the primary entity responsible for intervening early with environmental risk factors, has developed a collaborative model involving national, provincial, and municipal CDC branches. This model leverages the technical and data resources of the national CDC and utilizes local CDCs' accessibility to the general public. The initial work has rationalized a data information sharing mechanism and work content collaboration within the CDC, laying the groundwork for the subsequent implementation of operational tasks.

Construction of a joint working mechanism with the meteorological department: A collaborative mechanism has been developed in conjunction with the meteorological department, leveraging its established public service channel to create a joint early warning system. This system enhances the integration of health considerations into governmental early warning decisions while also broadening the demographic reach of these early warning interventions.

Construction of a joint working mechanism with medical institutions: This framework was designed with the aim of specifically identifying populations at risk from environmental factors. This targeted approach seeks to enhance the effectiveness and precision of risk warnings and interventions.

CHALLENGES AND PROSPECTS

Challenges

The work encountered two primary obstacles. First, the current early warning technology system lacked effective standardization. Previous health risk early warning effort did not possess consistent documentation, like guidelines for early warning technology or specifications for the release of early warning information. This significantly impeded the progress towards achieving systematic, scalable, and standardized early warning procedures.

Second, an operational mechanism for the prediction and alerting of health risks associated with environmental factors has yet to be established. Although early warnings for health risks attributed to environmental factors are crucial tools for public health services, they have not been integrated into the routine operations of environmental health work. The lack of an established mechanism for conducting early warning work leaves the respective responsibilities of all involved parties unclear, impeding the orderly initiation and seamless execution of these crucial tasks.

Outlook

The optimization and advancement of health-risk early warning and intervention systems for environmental risk factors are necessitated. Building on existing progress, the NIEH aims to enhance the early warning intervention model and compile technical specification documents that expand and refine mature health-risk early warning intervention technologies for air pollution, heatwaves, and cold spells. Concurrently, researches on other significant environmental risk factors, such as those related to water pollution, should be emphasized in order to establish health-risk early warning intervention technologies. Following the verification and evaluation of the intervention effects of the primary environmental risk factors' health risk early warning intervention technology, there is a clear need for further enhancement of the early warning model technology, health protection recommendations, and the early warning dissemination methods.

Second, there is a need for enhanced collaborative efforts across multiple departments. Agencies such as health, environmental protection, and data management should collaboratively strategize and establish a mechanism for sharing environmental risk factor monitoring and forecasting data, as well as early warning intervention information. There should also be well-defined communication channels established for the systematic dissemination of health risk early warnings to medical and health institutions. This would facilitate efficient early warnings for populations vulnerable to environmental risk factors and bolster the role of environmental health risk early-warning interventions in the precise management and control of sensitive diseases.

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Notifiable Infectious Diseases Reports

Reported Cases and Deaths of National Notifiable Infectious Diseases — China, December 2022*

Diseases	Cases	Deaths
Plague	0	0
Cholera	0	0
SARS-CoV	0	0
Acquired immune deficiency syndrome†	5,264	1,987
Hepatitis	72,630	51
Hepatitis A	532	0
Hepatitis B	59,498	24
Hepatitis C	11,050	26
Hepatitis D	16	0
Hepatitis E	1,187	1
Other hepatitis	347	0
Poliomyelitis	0	0
Human infection with H5N1 virus	0	0
Measles	79	0
Epidemic hemorrhagic fever	512	4
Rabies	6	20
Japanese encephalitis	3	0
Dengue	11	0
Anthrax	11	0
Dysentery	1,215	0
Tuberculosis	33,951	316
Typhoid fever and paratyphoid fever	234	0
Meningococcal meningitis	2	0
Pertussis	1,293	0
Diphtheria	0	0
Neonatal tetanus	3	0
Scarlet fever	1,026	0
Brucellosis	1,820	0
Gonorrhea	6,027	0
Syphilis	24,367	4
Leptospirosis	12	0
Schistosomiasis	28	0
Malaria	79	2
Human infection with H7N9 virus	0	0
Influenza	67,888	0
Mumps	3,839	0
Rubella	72	0

Continued

Diseases	Cases	Deaths
Acute hemorrhagic conjunctivitis	1,569	0
Leprosy	20	0
Typhus	36	0
Kala azar	9	0
Echinococcosis	144	0
Filariasis	0	0
Infectious diarrhea[§]	29,010	0
Hand, foot and mouth disease	27,747	0
Total	278,907	2,384

* According to the National Bureau of Disease Control and Prevention, not included coronavirus disease 2019 (COVID-19).

[†] The number of deaths of acquired immune deficiency syndrome (AIDS) is the number of all-cause deaths reported in the month by cumulative reported AIDS patients.

[§] Infectious diarrhea excludes cholera, dysentery, typhoid fever and paratyphoid fever.

The number of cases and cause-specific deaths refer to data recorded in National Notifiable Disease Reporting System in China, which includes both clinically-diagnosed cases and laboratory-confirmed cases. Only reported cases of the 31 provincial-level administrative divisions in Chinese mainland are included in the table, whereas data of Hong Kong Special Administrative Region, Macau Special Administrative Region, and Taiwan, China are not included. Monthly statistics are calculated without annual verification, which were usually conducted in February of the next year for de-duplication and verification of reported cases in annual statistics. Therefore, 12-month cases could not be added together directly to calculate the cumulative cases because the individual information might be verified via National Notifiable Disease Reporting System according to information verification or field investigations by local CDCs.

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