Nexus
Perspective

Comparing existing heat wave indices in identifying dangerous heat wave outdoor conditions

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https://doi.org/10.1016/j.ynexs.2024.100027

BROADER CONTEXT

Heat waves have emerged as a significant contributor to climate-induced heat-related mortalities, underscoring the urgency of recognizing their impact and severity. Proper identification of dangerous heat wave situations in various climatic and geographic regions is crucial for effective planning and mitigation strategies for heat waves. By examining recent heat waves in Asia, Europe, and the United States, this study emphasizes the limitations of available heat indices in detecting dangerous heat wave outdoor conditions, especially in low-humidity conditions. The present research focuses on the gap and need for developing global heat wave frameworks to effectively identify dangerous heat wave outdoor conditions over diverse climatic and geographic regions. This development will be helpful for climate scientists, health professionals, policymakers, and communities in developing mitigation strategies and raising awareness of heat risks.

SUMMARY

Heat waves are projected to become more intense and severe with global warming, impacting human health and deteriorating urban environments. Thus, understanding dangerous heat wave conditions in different climatic and geographic regions is essential. This study examines the effectiveness of six different temperature-humidity-based heat wave indices in identifying dangerous heat wave outdoor conditions, using recent heat wave events observed in Asia, Europe, and the United States as case studies. The lethal heat stress index performed better in identifying days with dangerous heat wave situations than the other indices in a low-humidity environment due to its ability to counteract the offsetting impact of air dryness. Our results suggest that selecting a heat wave index is crucial for identifying dangerous heat wave situations under different climatic, geographic, and meteorological conditions.

INTRODUCTION

Disasters of climatic origin significantly impact a country's economic loss, and around 4,432 billion USD loss was observed globally during 1990–2024.[1] A heat wave is a climate disaster, defined as prolonged periods of warm events that exceed a particular threshold for several consecutive days. A recent study shows that it has intensified across various regions of the world.[2,3] These events propagate space and time, characterizing a spatiotemporally contiguous propagation pattern.[4] The defining criteria for thresholds for identifying extreme situations of these events are location specific, and each county has its own standards. However, due to rapid increases in global temperatures and urbanization, it is necessary to revisit this threshold and adopt new criteria for identifying dangerous heat wave events. The UK Meteorological Department recently refined its historical climatological mean for defining extreme temperature events.[5]

Generally, two approaches are taken to identify heat wave days over a region. The first is the climatic approach, where the near-surface maximum air temperature is used to determine the warm period.[6] The news media used these maps to communicate information about extreme heat wave situations over a region.[7] Many epidemiological studies have investigated the effect of air temperature on heat wave mortality.[8] However, the lethality of a heat wave is not only a function of the maximum air temperature; it depends on both the air temperature and humidity.[9] In addition, the role of radiation and wind is also essential in heat stress estimation, as seen from the universal thermal climate index.[10] Under low-temperature conditions, people can still feel heat stress due to high humidity. The second perspective of heat waves, the psychological perspective, addresses human heat comfort. An increase in air humidity reduces the capacity of the human body to regulate its own body temperature via perspiration,[11] and severe fatality can occur even under low-temperature conditions. A recent global study confirmed that the threshold of lethal temperatures due to heat stress decreases with increasing humidity.[3] In view of this, researchers have developed various heat stress indices that account for other meteorological parameters, primarily humidity, to assess the impact of heat stress on human health. Heat waves can pose significant health risks to individuals, whether they are outdoors or indoors. Assessing both environments is crucial to fully understanding a population's exposure and vulnerability. Environment and meteorological conditions are essential for assessing outdoor heat, while building parameters like building materials, building morphology, overheating conditions, and air conditioning play a crucial role in calculating indoor heat stress. In this study, we mainly highlighted the importance of outdoor heat stress in identifying dangerous conditions that impact workers, who spend substantial time outdoors, such as construction workers and agricultural labourers.

The different indices have different thresholds for defining dangerous heat wave conditions. One of the disadvantages of this practice is that it may not apply to all climatic conditions. Moreover, the available heat indices do not significantly quantify the effect of moisture on heat stress.[12] With the progress of faster global warming, an index can fail to detect dangerous heat wave days due to using the old normal for calculating departure from the threshold. The threshold for defining dangerous heat wave conditions is based on the theoretical law of physics, and a recent study suggested that this threshold can be overestimated or underestimated based on background climate conditions,[13] gender, and age of people[14] and varies from country to country.[15] Even at 28°C, wet bulb temperature (WBT) in humid conditions can lead to severe strain and heat stroke conditions, although the threshold limit is 31°C.[13] Therefore, two typical questions arise: which heat wave indices should be selected? What is the role of climatic and background

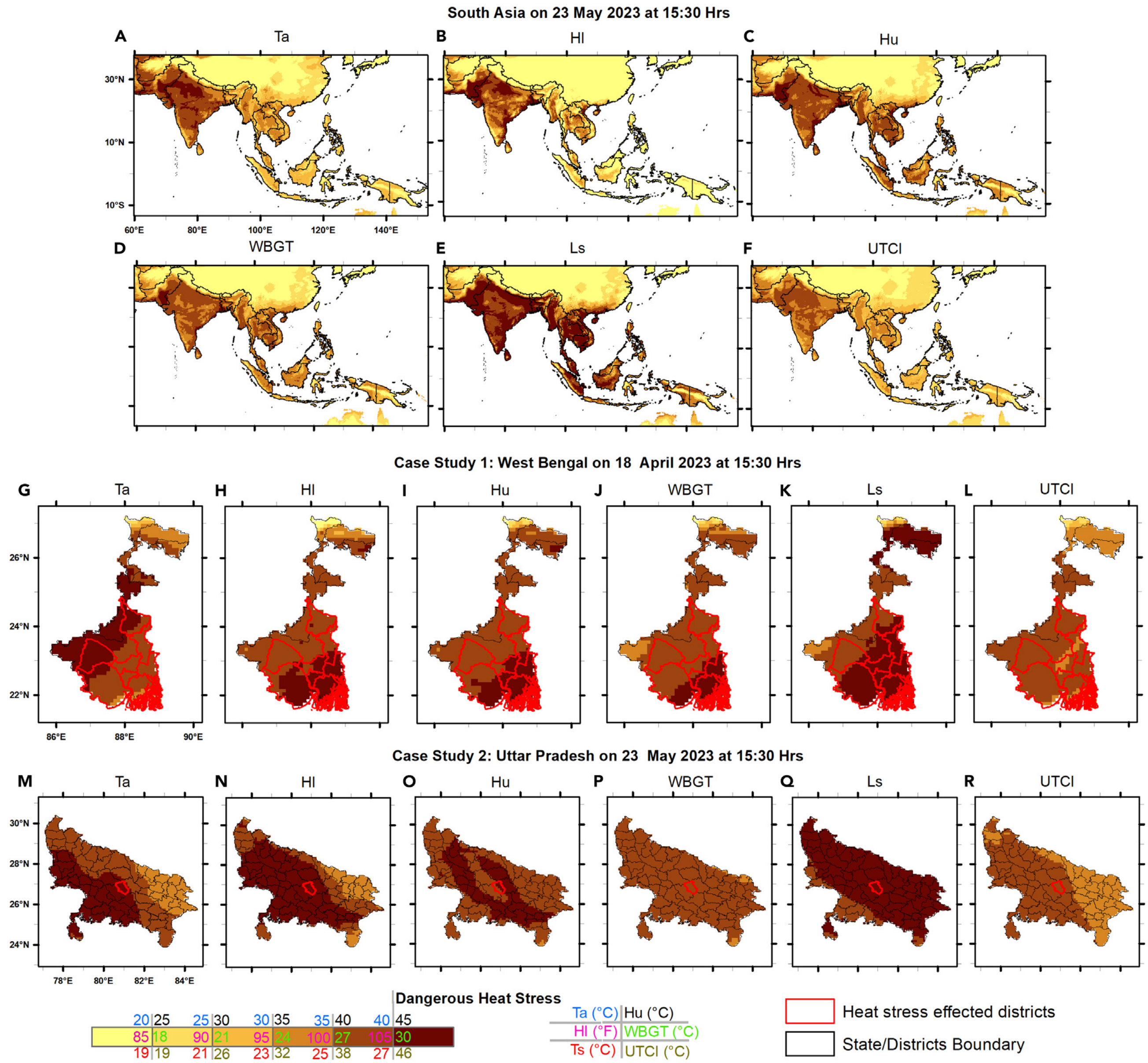

Figure 1. Spatial variation in the maximum daily temperature (Ta), humidity index (HI), humidity (Hu), wet bulb globe temperature (WBGT), lethal heat stress index (Ls), and universal thermal climate index (UTCI)

Spatial variation over (A–F) Southern Asia on May 23, 2023, (G–L) West Bengal on April 18, 2023, and (M–R) Uttar Pradesh on May 23, 2023, at 15:30 h local time. The red color marks the boundary of the affected district of West Bengal in case study 1 and the Lucknow district of Uttar Pradesh in case study 2 of dangerous heat wave conditions with the significant impact of heat-related fatalities, school closures, or electricity blackouts, as mentioned in various news media sources.

meteorological conditions in identifying dangerous heat wave conditions?

This research aimed to assess the feasibility of different heat wave indices for demarcating dangerous heat wave days using the maximum air temperature (Ta), humidity index (HI), humidex (Hu), wet bulb globe temperature (WBGT), lethal heat stress index (Ls), and universal thermal climate index (UTCI). Our focus is to examine the performance of these indices for an increasingly warming climate and how efficiently they can detect dangerous heat wave days in outdoor environment. Specifically, we selected recent heat wave conditions across different climatic and geographic regions, including the 2023 heat wave in Southern Asia, the summer 2022 heat wave in Spain, and the June 2022 heat wave in the United States. We calculated the heat wave during the peak hours of the day when the air temperature over the regions reached its maximum value (Figure S1). Using the daily ERA5-land hourly data of 2-m air temperature and 2-m dewpoint temperature at the peak hours, we estimated relative humidity following the formula of Alduchov et al.,[16] and then HI from Later Rothfusz,[17] Hu from Barnett et al.,[18,19] WBGT from Vecellio et al.,[20] Ls from Wouters et al.,[9] and UTCI from Bröde et al.[21] were calculated. Based on these indices, the dangerous heat wave conditions were determined, as suggested by previous studies. The detailed method adopted in this study can be seen in the experimental procedures section. This comparison can provide insight into how these selected indices can identify dangerous heat wave conditions. The results open a discussion on how a threshold needs to be selected in different climatic regions and background meteorological conditions to cope with a rapidly warming world.

Summer 2023 heat wave in Southern Asia

Southern Asia is one of the most populated regions in the world and has experienced extremely hot temperatures in recent years. The year 2023 marks a remarkable year in the climatological history of Asia, with higher

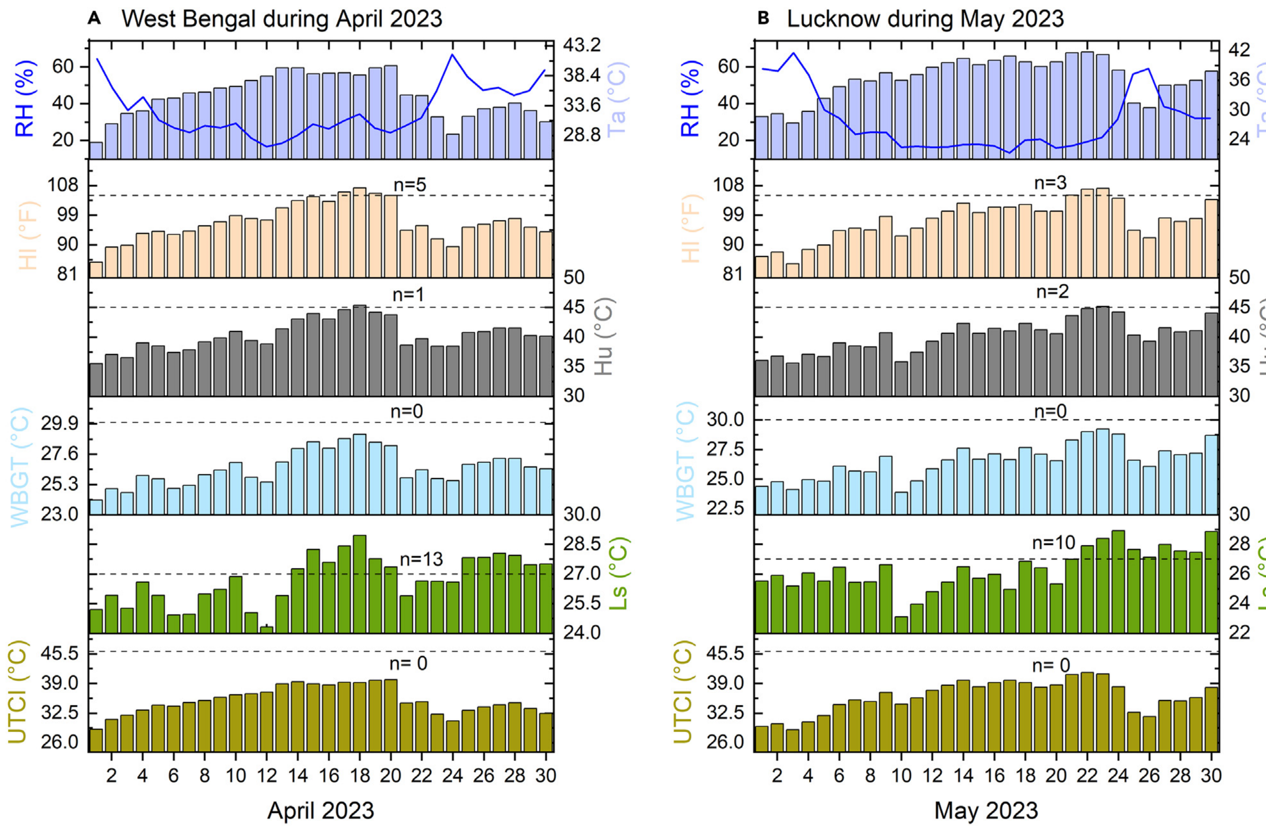

Figure 2. Monthly variations in the maximum daily temperature (Ta), relative humidity (RH), humidity index (HI), humidity (Hu), wet bulb globe temperature (WBGT), lethal heat stress index (Ls), and universal thermal climate index (UTCI)

Monthly variations over (A) the selected district of West Bengal, as shown in red boundary in Figure 1G, in April 2023, and (B) the selected district of Uttar Pradesh, as shown in red boundary in Figure 1M, in May 2023, at 15:30 h local time. The black horizontal dotted line marks the threshold of dangerous heat stress conditions for each index. *n* is the number of days with dangerous heat stress conditions in each index.

temperatures recorded in many parts of the region. In early April of 2023, several days of extreme heat stress conditions cause heatstroke to people outdoors. Many deaths have been reported in Asian countries, including northern India, southern China, Thailand, Myanmar, Laos, Bangladesh, etc.[22] On a hot summer day, when the all-time high-temperature record was broken in many Asian places, we applied the six selected indices to map the regions affected by dangerous heat stress situations (Figure 1). On May 23, 2023, the daily maximum temperatures were highest in western India and the Indo-Pak border region (Figure 1A). The major Indian states (Bihar, Uttar Pradesh, Jharkhand, Odisha, Andhra Pradesh, and West Bengal) have a high proportion of labourers and rural workers, who are forced to work outside even in high-temperature and humidity conditions. Additionally, Southeast China, Bangladesh, Myanmar, Thailand, Lao, and other countries were also affected by this heat wave. These events have led to many heat-related fatalities, and in some Indian places, even electricity blackout conditions have been detected. This signifies an extreme heat stress situation, which cannot be demarcated by the maximum daily temperature (Figure 1A) or the other temperature-humidity indices (HI, Hu, WBGT, and UTCI, as shown in Figures 1B–1D and 1F). However, the Ls index could differentiate most of the extreme heat stress-affected areas (Figure 1E) in these regions. Dozens of people have died in northern India,[23] mainly due to dangerous heat stress conditions, as clearly demarcated by Ls. Ls performed well compared to the other indices under low-humidity conditions, generally less than 30% in northern Indian states (Figure S2a). To determine the impact of different heat wave indices in demarcating dangerous heat wave conditions, we chose two case studies in Indian states, where heat wave conditions were dominant and significant.

Case study 1: April 18, 2023, heat wave in West Bengal, India

The third week of April 2023 witnessed a significant heat wave affecting most of the Asian region, marking the worst in Asian history.[24] These heat waves affected the Indian Peninsula, especially the coastal Indian states. West Bengal was significantly affected by the April heat wave, and the government announced the closure of schools from April 17 to 22, 2023, due to sweltering heat.[25] The majority of affected districts were located in southern West Bengal, which includes Kolkata, Howrah, Hooghly, Paschim Medinipur, Jhargram, North and South 24 Parganas, Nadia, and Murshidabad, as reported from various media coverage and by the Indian Meteorological Department (IMD).[26] A considerably higher daily maximum temperature was observed in the northwestern districts (Figure 1G), with no significant heat impact. The area under dangerous heat wave conditions is partially marked by the heat index (Figure 1H), humidity (Figure 1I), WBGT (Figure 1J), and almost none by UTCI (Figure 1L). Instead, the lethal heat stress index (Figure 1K) shows better spatial distribution of dangerous heat wave conditions across the different districts of West Bengal, as indicated by various media and the IMD. The humidity in the southern region (Figure S2b) plays a dominant role in enhancing the impact of heat stress. The temporal variation in the month shows that Ls performs well in identifying dangerous heat stress days during April 2023 over the affected district of West Bengal (Figure S3a) compared to the other indices (Figure 2A). In comparison to the other index, Ls identified 13 days of dangerous heat wave conditions, which is in line with news coverage and media reports.

Case study 2: May 23, 2023, heat wave in Uttar Pradesh, India

Later, in May 2023, the temperature surpassed 45°C in Uttar Pradesh, India, and blackouts were observed in some cities for more than 12 h, which led to people becoming uneasy and people starting to protest outdoors.[27] The International Disaster Database also defines Uttar Pradesh heat stress as a disaster that kills numerous people. One such city is Lucknow, where an incident occurred on May 23, 2023, and life for people in cities became unbearable due to a lack of air

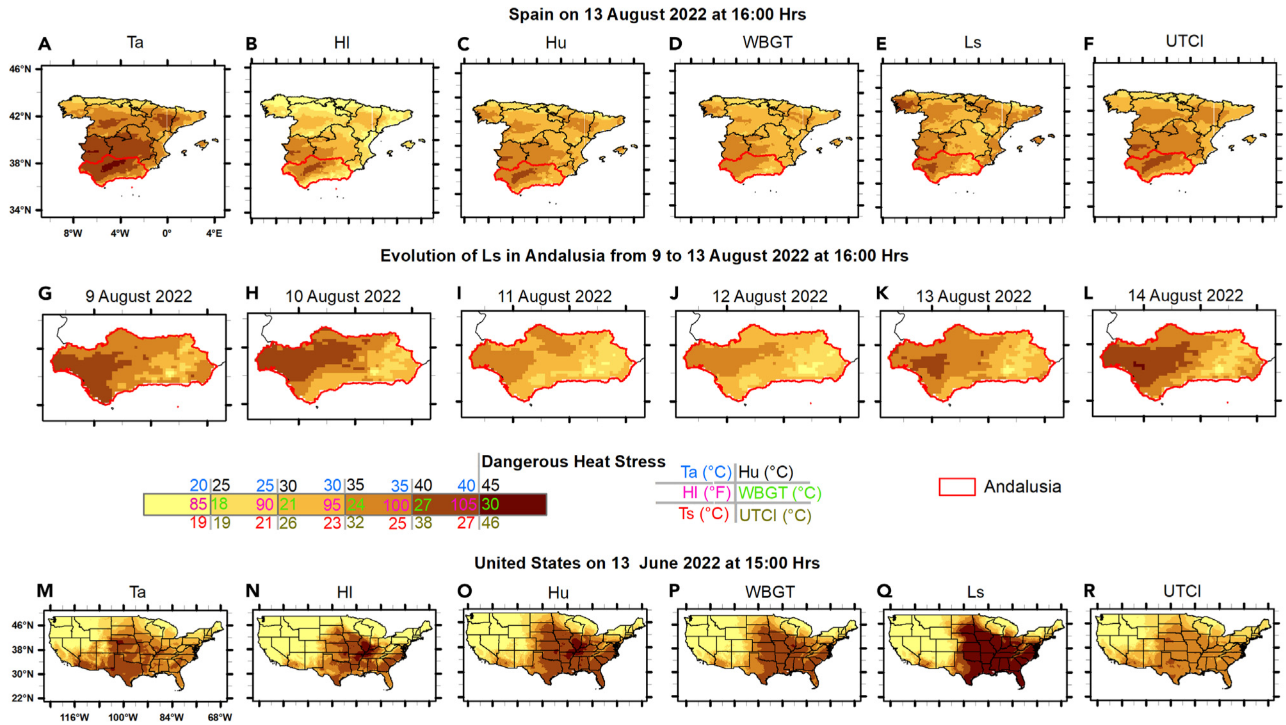

Figure 3. Maximum daily temperature (Ta), humidity index (HI), humidex (Hu), wet bulb globe temperature (WBGT), lethal heat stress index (Ls), and universal thermal climate index (UTCI) spatial variation

(A–F) Spatial variation over Spain on August 13, 2022.

(G–L) The evolution of Ls over the Andalusia district (marked in red) of southern Spain from August 9 to 14, 2022.

(M–R) June 2022 heat wave in the United States.

conditioning, fans, and even water. On May 21, 2023, the IMD issued a heat wave warning over 18 districts of northern and central Uttar Pradesh.[28] The spatial distributions of the Ta, HI, Hu, WBGT, and UTCI (Figures 1M–1P and 1R) did not cover most of the northern districts. However, the Ls distribution (Figure 1Q) seems to align with the IMD in identifying dangerous heat wave-affected districts. As seen in Lucknow on the 23rd May, the blackout day could be hazardous because it increases mortality and morbidity risk.[29] Therefore, we identified the days with dangerous heat wave in May by applying our selected six indices (Figure 2B) to the Lucknow district (Figure S3b). Compared to other indices, the Ls index can identify dangerous heat wave days (10 days) more efficiently despite low-humidity conditions over Lucknow (Figure S2c).

Summer 2022 heat wave in Spain

The summer of 2022 marked a record-breaking heat wave across major southern European countries, including Spain. Approximately 4,600 heat-related mortalities were reported in Spain from June to August 2022, most of which (nearly 98%) involved elderly people aged 65 and above.[30] Indistinct extreme situations were found mainly in the southern region of Spain, as in the Andalusia district. The highly urbanized cities of Andalusia, such as Seville and Cordoba, have faced major casualties due to the combined effect of urban heat islands, which increase the temperature of the urban environment. According to the heat index, humidex, and WBGT, no dangerous heat wave conditions were detected in Spain, even in Andalusia, on a warm day (August 13) of the summer month of 2022 (Figures 3B–3D). Moreover, the recorded daily maximum temperature was also low, with a mean value of 30.4°C, over Spain and 39.8°C over Andalusia (Figure 3A). Indeed, the Ls and UTCI indicate dangerous heat wave conditions in the Andalusia district, especially in the southwestern part (Figures 3E and 3F). The evolution of the dangerous heat wave situation can easily be traced to Andalusia a few days earlier (Figures 3G–3L). The temporal analysis of indices over Andalusia clearly identifies dangerous heat wave days (8 days in August 2022) using the Ls indices (Figures S4A and S5).

June 2022 heat wave in the United States

In June 2022, much of the United States experienced an intense and prolonged heat wave that broke numerous temperature records across the country. The heat wave first emerged in the southwestern states in early June, with temperatures soaring above average. By mid-June, the high-pressure system responsible for the extreme heat had expanded, affecting a large swath of the central and eastern United States, as revealed by the spatial distribution of Ls (Figure 3Q). The maximum daily temperature (Figure 3M) and the other four indices (Figures 3N–3P and 3R) do not conveniently reflect the dangerous heat wave situation. The extended duration of the heat wave, lasting over 2 weeks in some areas, posed significant health risks, especially for vulnerable populations like the elderly, young children, and those without access to adequate cooling. Heat-related illnesses, such as heat exhaustion and heat stroke, increased dramatically during this period. The temporal variation in Ls revealed a deadly heat wave situation in the second week from June 10 to 25, 2022 (Figures S4B and S5). This result aligns with the published report of the Society of Actuaries Research Institute, United States.[31]

DISCUSSION

The role of humidity plays a crucial role in identifying the impact of heat stress on human health.[32,33] In the literature, many temperature-humidity indices are available. Each index has its strengths and limitations. In this study, we evaluated the performance of five different temperature-humidity-based heat stress indices and maximum daily temperatures in identifying dangerous heat wave situations under low-humidity conditions. The outcome suggests that the recently developed Ls shows better results in identifying dangerous heat wave days. The Ls index performs well under low-humidity conditions due to the addition of a second term to the WBT, which removes the impact of air dryness.[9] To confirm our results, we chose two case studies from India's recent 2023 heat wave, where significant heat-related mortality, electricity blackouts, and school closure episodes were reported in various news media and published reports. The results of both case studies confirmed that the role of the Ls index is crucial in identifying dangerous heat wave days under low-humidity conditions. The other index had developed earlier, and the threshold set for dangerous heat wave conditions would be more specific to that time's climatic conditions in that geographic region. However, with rapid development in global warming, where each year is hotter than the previous year, there is an urgent need to revisit the threshold and adopt a new global criterion for defining dangerous heat wave limits based on different climatic conditions and the adaptability of humans based on sex and age. Currently, the available frameworks for assessing heat waves are specific to individual countries, lacking a standardized global approach. It is crucial to address this gap and prioritize the development of heat wave rankings and nomenclature that consider the diverse climatic conditions across various geographic regions worldwide. The urgent need for a standardized international framework stems from the fact that heat stress affects populations across the globe differently, depending on the local climate and adaptive capacities.

The proper definition of the heat wave threshold for dangerous conditions is necessary so that proper mitigation strategies can be taken to reduce the impact of deadly heat stress on human health, and cautious adaptation measures can be taken to cope with the increasing number of heat waves events. Instead of a theoretical threshold, it is better to define physiological-based human impacts via validation with real heat-related mortality data from major heat wave events. In addition to people's age, preexisting health conditions, socioeconomic status, living environment, and climatic and background meteorological conditions should also be considered when formulating a global heat stress risk framework. Mapping heat exposure and identifying vulnerable groups are significant steps in managing heat risks in future climate scenarios. It is noteworthy to mention that most of the heat-related mortalities occur in indoor environments, while the available heat indices considered in this study are based on outdoor heat mapping data provided by climate services. This distinction is an important consideration, as it highlights the potential gap between the commonly reported outdoor heat data and the often-overlooked indoor heat-related impacts. Integrating this perspective could help bridge this gap and provide a more comprehensive understanding of heat-related risks and their public health implications. A recent study showed that well-known UTCI also fails to detect heat-mortalities in cold climates and building factors like overheating hours, use of air conditioning, etc.[34] Climate heat waves pose a serious threat to public health, especially for older individuals in long-term care homes, and this study raised an issue on the need to develop a new approach to generate health-based overheating limit criteria for these buildings that better account for the risks compared to traditional comfort-based methods.[35,36]

Climate experts and health scientists must work together to reduce the impact of heat stress on human health and life. This information not only helps climate experts and health scientists but also provides significant insights for public health officials and policymakers to develop strategies that mitigate heat stress impacts and protect vulnerable populations. Integrating climate science and health perspectives allows us to understand better climate-related health risks considering special geographic regions. Understanding the relationships between climate change, heat stress, and human health is vital for developing effective adaptation and mitigation strategies. This could only be achieved with interdisciplinary collaboration between climate scientists, health professionals, policymakers, and communities to safeguard public health in a changing climate.

Conclusion

In summary, selecting a suitable heat index is crucial for reliably detecting dangerous heat wave conditions across varied climatic settings. Using real examples of heat wave events, we compare different temperature-humidity-based heat indices for detecting dangerous heat wave days. These results suggest that the lethal heat stress index improved the ability to identify dangerous heat wave conditions in low-humidity regions. The development of a global heat risk framework and nomenclature for heat risk early warning are recommended. With rapid global warming, local authorities should adopt more sophisticated heat stress mitigation and adaptation measures. The results of the present study open a broader discussion on the feasibility of using existing heat wave indices for identifying dangerous heat wave situations under different climatic, geographic, and meteorological conditions.

EXPERIMENTAL PROCEDURES

Resource availability

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Prof. Qihao Weng (qihao.weng@polyu.edu.hk).

Materials availability

This study did not generate new unique materials.

Data and code availability

The hourly ERA5 data used in this study can be obtained from the Copernicus Climate Database, available at https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview. The Python code for the data preprocessing and estimation of different heatwave indices can be obtained from the corresponding author upon request.

Data and methods

Reanalysis data

To estimate the different heatwave indices, we used hourly ERA5 data at a spatial resolution of $0.1^\circ \times 0.1^\circ$ (9×9 km) from 1950 to the present. The present study uses daily 2-m air temperature (T_a) and 2-m dewpoint temperature (T_d) at peak hours of the day with maximum T_a and T_d. Before analyzing the heat wave event at a location, we first perform a diurnal analysis of selected parameters (T_a and T_d) to determine the peak hours at that location, and then we estimate the heat wave indices.

Selection of heat wave indices

The present study focuses on six different heat wave indices, which can be easily estimated directly or indirectly from the two selected parameters. The six indices include maximum air temperature (T_a), Steadman's heat index (*HI*), humidex (*Hu*), wet bulb globe temperature (*WBGT*), lethal heat stress index (L_s), and universal thermal climate index (*UTCI*). Different heat wave indices may rely on varying combinations of meteorological, biophysical, or physiological variables as their underlying inputs. The choice of which indices to employ can significantly impact the data requirements and analytical approach. For instance, T_a solely depends on ambient temperature, *HI* depends on air temperature and relative humidity, *Hu* is based on air and dew point temperature, *WBGT* is based on WBT and air temperature, L_s is based on wet bulb temperature with humidity correction, and *UTCI* is based on air temperature, humidity, wind speed, and radiation. Additionally, the assessment basis of different indices in different tables (Table 1) represents the varying nature of selected heat wave indices, and this study aims to highlight the nuanced differences among the selected heat wave indices.

First, we estimated the relative humidity (*RH*) in percent based on the 2-m air temperature and dewpoint temperature (in $^\circ$C) using Equation 1 following Alduchov et al.,[16] with a relative error of 0.384% (-40°C to -50°C).

$$RH = 100 * exp\left(17.625 * \left(\frac{T_d}{(243.04+T_d)} - \frac{T_a}{(243.04+T_a)}\right)\right)$$

(Equation 1)

Heat Index (*HI*) was initially developed by Steadman[39] following the guidelines of the US National Oceanic and Atmospheric Administration (NOAA) based on air temperature and relative humidity. Later, Rothfusz[17] modified the equation by multiple regression analysis, as shown in Equation 2:

Table 1. Criteria for identifying dangerous heat stress conditions of the five selected heat indices

Heat stress indicator	Assessment base	Dangerous heat wave criteria	Severity level	Reference
Steadman's heat index (*HI*)	degree of danger, effect on the human body	$HI > 105\,^\circ F$	extreme danger	National Oceanic and Atmospheric Administration (NOAA)[37]
Humidex (*Hu*)	thermal discomfort level	$Hu > 45\,^\circ C$	heat stroke imminent	Schwingshackl et al.[38] and Canadian Centre for Occupational Health and Safety (CCOHS)[19]
Wet bulb globe temperature (*WBGT*)	effect of heat on the human body and work intensities level	$WBGT > 30\,^\circ C$	no work at all, 100% rest/hour	Vecellio et al.[20]
Lethal heat stress index (L_s)	soil drought on heat stress	$L_s > 27\,^\circ C$	deadly	Wouters et al.[9]
Universal Thermal Climate Index (*UTCI*)	thermal stress from UTCI model output	$UTCI > 46\,^\circ C$	extreme	Bröde et al.[21]

$$\begin{aligned} HI = & -42.379 + 2.04901523 * T_a + 10.14333127 * RH \\ & - 0.22475541 * T_a * RH - 6.8378 * 10^{-3} * T_a{}^2 \\ & - 5.48172 * 10^{-2} * RH^2 + 1.229 * 10^{-3} * T_a{}^2 \\ & * RH + 8.528 * 10^{-4} * T_a * RH^2 - 1.99 * 10^{-6} * T_a{}^2 * RH^2, \end{aligned} \quad \text{(Equation 2)}$$

where T_a is in °F, *RH* is in %, and *HI* is in °F. If *RH* is less than 13% and T_a is between 80 and 112°F, then some adjustment is subtracted from *HI* following the NOAA guidelines.[37]

Humidex (*Hu*) is estimated from the 2-m air temperature (T_a) and 2-m dew point temperature (T_d) following the equation developed by Barnett et al.,[18,19] as shown below in Equation 3:

$$Hu = T_a + 3.394444 * exp\left(19.833625 - \frac{5417.7530}{T_d}\right) - 5.555556, \quad \text{(Equation 3)}$$

where T_a is in °C, T_d is in K, and the obtained Hu will be in °C.

Wet Bulb Globe Temperature (*WBGT*) is calculated with the help of the WBT and air temperature using Equation 4, assuming that the globe temperature equals the dry bulb temperature under radiation-free indoor conditions.[20]

$$WBGT = 0.7 * WBT + 0.3 * T_a \quad \text{(Equation 4)}$$

where *WBT* is in °C, the air temperature (T_a) is in °C, and the output *WBGT* is also in °C. Following the method of Stull (2011),[40] *WBT* is calculated using Equation 5 with the help of T_a (in °C) and *RH* (in %).

$$\begin{aligned} WBT = & T_a * \arctan\left[0.151977 * \left((RH + 8.313659)^{\frac{1}{2}}\right)\right] \\ & + \arctan(T_a + RH) - \arctan[RH - 1.676331] \\ & + 0.00391838 * RH^{\frac{3}{2}} * \arctan(0.023101 * RH) - 4.686035 \end{aligned} \quad \text{(Equation 5)}$$

Lethal Heat Stress Index (L_s) developed by Wouters et al. (2022)[9] is calculated using the wet bulb temperature (*WBT*) as estimated in Equation 5 in °C and the relative humidity (*RH*) in % from Equation 1. The estimated L_s will be in °C, as obtained from Equation 6.

$$L_s = WBT + 4.5\left(1 - \left[\frac{RH}{100}\right]^2\right) \quad \text{(Equation 6)}$$

Universal Thermal Climate Index (*UTCI*) is based on detailed modeling of heat balance, incorporating temperature, humidity, wind speed, and radiation.[41] UTCI was calculated using the UTCI polynomial as described by Bröde et al. (2012).[21] Using the limit specified to the UTCI polynomial,[21] and considering the minimum reference conditions (wind speed [*va*] = 0.5 m/s at 10 m and mean radiant temperature [T_r] = 0°C),[12] the UTCI (in °C) is estimated from Equation 7 using air temperature (T_a) and vapor pressure (*pa*), which is calculated from relative humidity (%) using the Magnus formula.

$$UTCI\,(T_a, T_r, va, pa) = T_a + offset(T_a, T_r, va, pa) \quad \text{(Equation 7)}$$

Criteria for defining dangerous heat wave conditions from different indices

Extreme or dangerous heat wave situations are identified based on the upper thresholds of different indices, as suggested in the previous literature. The criteria for identifying dangerous heat wave conditions of the five selected heat indices are shown in Table 1.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.ynexs.2024.100027.

ACKNOWLEDGMENTS

We acknowledge the financial support of the Global STEM Professorship of Hong Kong SAR Government (P0039329), the Research Talent Hub of the Innovation and Technology Fund of Hong Kong (P0039329), and the Hong Kong Polytechnic University (P0046482 and P0038446) for this research. The authors are grateful to the editors and reviewers for their constructive comments and suggestions that helped improve the manuscript.

AUTHOR CONTRIBUTIONS

P.M. and Q.W. conceived the idea of the perspective article, P.M. performed the analysis and drafted the initial manuscript, and Q.W. reviewed and modified the manuscript. Both P.M. and Q.W. agreed with the final submission version of the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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