JEVNAH
Journal of Evidence-based Nursing and Public Health
JEVNAH 3(2): 117–133
ISSN 3048-2615

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

The impact of heatwaves on the incidence of heatstroke in the elderly and children: An environmental health epidemiological study

Fadilah Habibull Hamda[1,*], Citta Zahra Primalia[1], Yolanda Safitri[2], Soraya Permata Sujana[3]

[1] *Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia;*
[2] *Department of Health Education and Behavioral Science, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia;*
[3] *Department of Environmental Health of Epidemiology, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia.*
*Correspondence: habibulhamdafadilah@gmail.com

Received Date: December 22, 2025 Revised Date: August 26, 2026 Accepted Date: August 27, 2026

ABSTRACT
Background: The latest report from the Intergovernmental Panel on Climate Change (IPCC) shows that heatwaves have increased over the past 50 years. Heatstroke is a life-threatening condition defined by a failure in heat dissipation, resulting in a body core temperature of more than 40 °C (104 °F) and associated with neurological disorders, ranging from mild changes in mental status to coma. **Methods:** This study uses the systematic literature review (SLR) method and follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The review is structured using the PECO framework based on 4 main components: participants (human), exposure (heatwave), comparator (elderly and children) and the outcomes (heatstroke). **Findings:** Exposure to heatwaves has been shown to significantly affect vulnerable groups such as the elderly and children, where the elderly group is the most affected due to various factors, including organ dysfunction and congenital diseases that worsen the situation. **Conclusion**: In the future, it is necessary to strengthen mitigation effort related to extreme weather forecasts, enabling communities to adjust their outdoor activities. **Novelty/Originality of this article:** The novelty of this article is to describe how the heatstroke impact the vulnerable group of elderly and children.

KEYWORDS: heatwave; heatstroke; vulnerability.

1. Introduction

The climate crisis, recognized by the World Health Organization as one of the greatest threats to human health in the 21st century, is fundamentally reshaping global disease patterns and health risks. Its impacts are both direct and indirect, mediated by environmental, socio-economic, and demographic factors. Among these, rising temperatures and the increasing frequency and intensity of heatwaves have emerged as critical drivers of morbidity and mortality worldwide. Extreme heat events contribute to a wide range of adverse health outcomes, including dehydration, cardiovascular stress, respiratory complications, and increased mortality. Recent evidence highlights a growing

Cite This Article:
Hamda, F. H., Primalia, C. Z., Safitri, Y., &Sujana, S. P. (2026). The impact of heatwaves on the incidence of heatstroke in the elderly and children: An environmental health epidemiological study. *Journal of Evidence-based Nursing and Public Health, 3*(2), 117–133. https://doi.org/10.61511/jevnah.v3i2.2026.2625

Copyright: © 2026 by the authors. This article is distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

burden of heat-related health risks, with extreme heat now recognized as a leading cause of weather-related deaths globally (Yoeli et al., 2025). In recent years, the number of heat-related illnesses has increased each year. This rise is linked to factors such as climate change, low heat tolerance, air pollution, high humidity, and limited access to air conditioning. One example of a heat-related illness is heatstroke (Han et al., 2022). Heatstroke is a life-threatening condition defined by a failure in heat dissipation, resulting in a body core temperature of more than 40 °C (104 °F) and being associated with neurological disorders, ranging from mild changes in mental status to coma (Canel et al., 2016; Kania & Hess, 2025; Toosty et al., 2021; Wijerathne et al., 2016). A study published in The Lancet-Planet Health shows an upward trend in additional mortality caused by rising global temperatures, from 0.83 % in 2000–2003 to 1.04 % in 2016–2019 (Zhao et al., 2021).

The molecular mechanisms underlying heatstroke are complex and involve multiple processes triggered by extreme heat. These include protein damage, disruption of normal cellular balance, oxidative stress, and impaired mitochondrial function. In addition, heat stress leads to the release of damage-associated molecular patterns (DAMPs), which activate immune responses. At the same time, several forms of regulated cell death, such as apoptosis, necroptosis, pyroptosis, and ferroptosis are activated, further worsening tissue damage. Important factors involved in these processes include heat shock proteins, inflammatory cytokines, and reactive oxygen species (Ferrer & Iba, 2025).

Various factors contribute to the occurrence of heatstroke; for example, environmental factors such as high temperature and humidity, human factors such as dehydration, the presence of comorbidities, delayed heat acclimatization, aging, and activity factors such as exercise and working in hot environments. Heatwaves at the beginning of the summer generally result in higher death rates than those at the end of the summer. Important risk factors for higher mortality include advanced age; low social status; addictive disorders; restricted mobility; the presence of pulmonary, cardiovascular, or psychogeriatric disease; and chronic renal disease. People who live high up in a building or live alone also have a statistically increased risk. It is now widely accepted that heat stress is particularly dangerous to old, frail, and often (multi-) morbid people and this is a generalized problem in geriatrics (Leyk, 2019). However, an elevated body temperature may not be sufficient to diagnose heatstroke. Heatstroke associated symptoms should also include fatigue, hot and dry skin, nausea, vomiting, diarrhea, dizziness, reddened face, difficulty breathing, seizures, confusion, and damage to multiple organs. The main difference between mild and severe cases is the presence or risk of loss of consciousness (Zhang et al., 2024).

There are two types of heatstroke, namely classic and physical activity. Classic heatstroke is generally caused by high ambient temperatures, progresses slowly over several days, and can be characterized by delirium, seizures, or coma (Wijerathne et al., 2016). The risk of developing heatstroke is known to be increased by both intrinsic and extrinsic factors. Intrinsic factors include the illnesses and genetic predispositions of individuals. Extrinsic factors include meteorological conditions and excessive clothing (Morioka et al., 2025). Of the various external factors, meteorological conditions play a crucial role in the onset of heatstroke. It is widely known that the number of heatstroke patients increases as the air temperature increases. This condition mainly occurs in elderly people who are frail due to chronic illnesses. Heatstroke due to physical activity mainly affects young and active people such as marathon runners, athletes, or military personnel (Shu-Yuan et al., 2020). Patients have a better chance of recovery if their core body temperature is lowered below 40 °C within 30 minutes of onset. Delayed cooling can cause long-term problems such as memory loss, speech or movement disorders, and a higher risk of death. The development of heatstroke involves not only problems with body temperature control but also inflammation, oxidative stress, cell damage, and cell death (Oka et al., 2025; Zhang, 2024). Heatstroke affects everyone, especially the vulnerable populations, such as outdoor workers, athletes, elderly, and children. Elderly individuals have a high risk of heatstroke because the thermoregulatory function of the human body declines with age. In addition, elderly individuals are more likely to suffer from cardiovascular diseases and diabetes, which increase the risk of severe heatstroke (Sato et al., 2020). Children are particularly at risk due to their unique physiological responses to heat, such as higher heat generation per unit body mass and a greater surface area-to-mass ratio, which increases their heat absorption

In the face of climate change challenges, many areas in some parts of the world are experiencing rising temperatures, further exacerbating health problems such as increasing the risk of pain and death from intense heat on a sustained basis (Schmeltz et al., 2016; Toloo et al., 2014; Wright et al., 2019). The latest report from the Intergovernmental Panel on Climate Change (IPCC) shows that heat waves have increased over the past 50 years (Arsad et al., 2022). As the global climate warms and exposure to high temperatures rises, the incidence of heatstroke among older adults will rise (Otani et al., 2021). In particular, climate change including global warming has contributed to the recent increase in the incidence of heatstroke (Otani et al., 2021). It is estimated that up to 1.2 billion people worldwide will be at risk of heatstroke by 2100 if global warming continues at this rate (Li et al., 2025). Some groups are at high risk, such as people with low economic conditions, preexisting respiratory and cardiovascular diseases, as well as the elderly and children (Toloo et al., 2014). Looking at the dangers posed by extreme heat and heatwaves, many researchers are trying to understand the vulnerability factors in the population (Coates et al., 2014). Vulnerability in humans, especially vulnerable groups to climate change and its variability, is complex and does not yet have a generally accepted definition (Sharma & Ravindranath, 2019).

Despite growing recognition of heat-related health risks, significant gaps remain in understanding how vulnerability is distributed across populations and how it can be effectively addressed through policy and practice. Existing studies often focus on general population-level trends or specific clinical outcomes, with less attention given to comparative vulnerability across age groups or the interaction between environmental exposure and social determinants of health. Furthermore, while heat-health warning systems and climate adaptation strategies are increasingly being implemented in many countries, their effectiveness in reaching and protecting the most vulnerable populations remains uneven.

From a policy perspective, this gap is particularly important. Public health responses to heatwaves, such as early warning systems, community outreach, and emergency preparedness, require precise identification of high-risk groups and contexts. Without a nuanced understanding of vulnerability, interventions risk being too generalized, potentially overlooking those most in need. In addition, climate adaptation policies must be grounded in evidence that reflects not only environmental risks but also social inequalities and demographic dynamics. Therefore, this study seeks to address these gaps by examining the impact of heatwaves on vulnerable populations, with a specific focus on children and older adults. More specifically, this study is guided by three research questions: (1) How do heatwaves affect health outcomes among children and older adults? (2) What factors contribute to increased vulnerability to heat-related illnesses in these populations? (3) How can these findings inform more targeted and effective public health interventions and climate adaptation policies?

By addressing these questions, this study aims to contribute to a more comprehensive understanding of heat-related vulnerability in the context of climate change. The findings are expected to provide important insights for policymakers, public health practitioners, and other stakeholders in designing targeted heat-health action plans. This includes improving early warning systems, developing age-specific prevention strategies, and strengthening community-level resilience. Ultimately, this research seeks to support more equitable and effective responses to the growing health risks posed by extreme heat.

2. Methods

This study used a systematic literature review (SLR) approach following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. The review was structured using the participants, exposure, comparator, outcome (PECO) framework, which guided the formulation of the research question and eligibility criteria. The components included: participants (humans), exposure (heatwaves), comparator (children and elderly populations), and outcomes (heatstroke incidence and related health impacts). A comprehensive literature search was conducted across three major electronic databases, namely ProQuest, Scopus, and PubMed, and was supplemented by manual searching through Google Scholar to identify additional relevant studies. The search was limited to peer-reviewed articles published in English between 2014 and 2025. Boolean operators were used to refine the search strategy by combining key terms such as “heatwaves” AND “heatstroke” AND (“elderly” OR “older adults”) AND (“children” OR “pediatric”). To ensure completeness, the reference lists of selected articles were also manually screened to identify potentially relevant studies not captured in the initial database search.

The study selection process followed the four stages outlined in the PRISMA framework: identification, screening, eligibility, and inclusion. During the identification stage, a total of 1,515 articles were retrieved. After removing 45 duplicate records, 1,470 articles remained for title and abstract screening. In the screening stage, 1,448 articles were excluded due to irrelevance to the research topic or lack of alignment with the PECO criteria. A total of 22 articles were then assessed for full-text eligibility. Of these, three articles were excluded due to lack of full-text access, and 14 were excluded for not meeting the predefined inclusion criteria. In addition, three relevant articles were identified through manual searching via Google Scholar. Ultimately, 8 studies met all eligibility criteria and were included in the final synthesis, as illustrated in the PRISMA flow diagram (Figure 1).

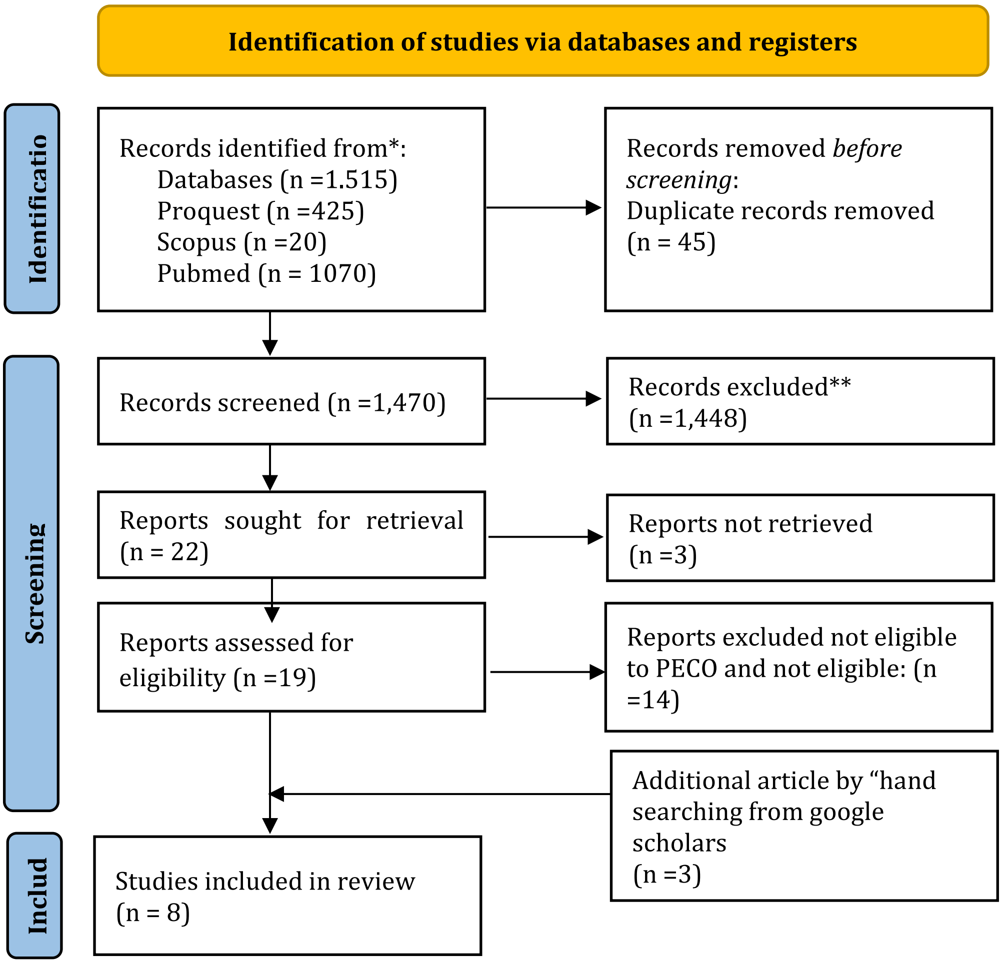

Fig. 1. PRISMA flowchart of the bibliographic research

The inclusion criteria consisted of (1) peer-reviewed research articles, (2) studies involving human participants, (3) studies examining heatwaves as the primary exposure, (4) studies reporting heatstroke or heat-related health outcomes, and (5) studies focusing on vulnerable populations, particularly children and the elderly. Exclusion criteria included (1) non-English publications, (2) review articles, editorials, or commentaries, (3) studies not directly addressing heatwaves or heatstroke, and (4) studies not involving the target populations. To ensure the methodological quality of the included studies, a critical appraisal was conducted using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for quantitative studies. Each article was evaluated based on criteria such as study design, sampling methods, measurement validity, identification of confounding factors, and appropriateness of statistical analysis. Each item was rated as "yes," "no," "unclear," or "not applicable." Studies were not excluded solely based on quality scores; however, the appraisal results were used to interpret the strength and reliability of the evidence. To enhance consistency and reduce subjectivity in the selection and appraisal process, inter-rater reliability was assessed using Cohen's Kappa coefficient during the full-text screening stage. The Kappa test was used to evaluate agreement between reviewers, with values above 0.75 indicating strong agreement and supporting the reliability of the selection process.

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Sources	ProQuest, Scopus, PubMed	Another database
Year	2014-2025	Studies published before or after this period
Languages	English	Other languages
Population (P)	Human	Other
Intervention/Exposure (E)	Heatwaves	Other
Comparative (C)	Elderly and children	Adult, teenagers or athlete etc.
Outcome measure (O)	Heatstroke	Mortality
Study/studies (S)	Quantitative	Other
Type of publication	Academic Journal, open access, free, and publish in public health field	Other publication (conference abstract and etc)

Potential sources of bias were considered throughout the review process. Selection bias was minimized through the use of predefined inclusion and exclusion criteria and a structured screening approach. Publication bias was addressed by searching multiple databases and incorporating manual searches to capture a broader range of studies. In addition, information bias was reduced by including only studies with clearly defined exposure and outcome measures. The use of a standardized appraisal tool further supported the identification of methodological limitations within individual studies.

Data extraction was conducted systematically using a standardized form to capture key information from each included study, including author(s), publication year, study location, population characteristics, exposure details, outcome measures, and key findings. Due to heterogeneity in study designs, populations, and outcome measurements, a quantitative meta-analysis was not feasible. Therefore, a narrative synthesis approach was adopted. The findings were analyzed thematically, focusing on patterns of vulnerability, differences between children and elderly populations, and the relationship between heatwave exposure and heatstroke incidence. Studies were grouped based on population type and outcome characteristics, allowing for comparison across studies and identification of consistent trends as well as variations in findings.

3. Results and Discussion

3.1 Overview

Based on the extraction result from the PRISMA, 8 articles were identified that align with the PECO and meet the inclusion criteria as presented in Table 1. In general, the study design used in these articles is modeling and ecological studies and time series. Overall, the eight articles indicate that the elderly and children are vulnerable to heatstroke associated with heatwaves exposure, especially in the elderly.

Table 2. Data extraction from included studies

Author	Title	Country	Study Design	Sample/ population	Results
Ou et al. (2023)	Risk of heatstroke in healthy elderly during heatwaves: A thermoregulatory modeling study	China	Using the modified thermoregulatory model	Young and elderly adults.	In the elderly age group, they showed worse performance in dissipating heat, increasing the risk of heatstroke compared to the age group of children and adults.
Hess et al. (2014)	Summertime Acute Heat Illness in U.S. Emergency Departments from 2006 through 2010: Analysis of a Nationally Representative Sample	United States	Analysis of a Nationally Representative Sample	All Population from 2006 to 2010 that each year approximately 300 thousand people per year.	Heatstroke had an ED CFR of 99.4/10,000 (95% CI: 78.7, 120.1) visits and was diagnosed in 77.0% of deaths. Adjusted odds of hospital admission or death in the ED were higher among elders, males, urban and low-income residents, and those with chronic conditions.
Oka et al. (2023)	Potential effect of heat adaptation on association between number of heatstroke patients transported by ambulance and wet bulb globe temperature in Japan	Japan	A quasi-Poisson regression model combined with the distributed lag non-linear model (DLNM)	All Population in all 47 Japan prefectures by age group from 2015 to 2019 because the availability data in all periods from 2008 – 2021 not available for may before 2015 and 2020-2021 might have bias because of drastic chages in life due to COVID 19	The results of the study showed that the risk group was the elderly with an age of ≥65 years with R2 = 0.64 which was interpreted as 64% of the temperature resulting in the incidence of heatstroke in the age group of ≥65 years. However, the age group of children is also vulnerable if they are active in outdoor activities.

Toosty et al. (2021)	Heat health risk assessment analysing heatstroke patients in Fukuoka City, Japan	Fukuoka, Japan	The Poisson regression model	Data was originally recorded annually by all seven fire departments in Fukuoka City between 1 April and 31 October from 2013 to 2018. This highly populous city has a total population of 1,538,000	Results indicated that there was a positive association between the resulting risk factors and the probability of heatstroke occurrence. The elderly of Fukuoka City aged 70 years or older were found to be the most vulnerable to heatstroke.
Bai et al. (2014)	The effects of summer temperature and heat waves on heat-related illness in a coastal city of China, 2011–2013	China	using a distributed lag non-linear model (DLNM)	In 2010, the population of the city was 7,605,689 (51.1% men; 48.9% women). Overall, a total number of 3862heat-related illnesses were included during June–August over the period 2011–2013 in Ningbo, China	Because the temperature fluctuates in each year so that there is also a difference in risk in age groups, the impact by age group is more inconsistent over three years. In 2011, the most affected groups were those aged 0–15 years, while the middle-aged and elderly populations were at higher risk of developing heat-related conditions in 2012 and 2013, respectively. However, all age groups are at risk.
Otani et al. (2021)	The Effect of Minimum and Maximum Air Temperatures in the Summer on Heat Stroke in Japan: A Time-Stratified Case-Crossover Study	Japan	Ecological study using a logistic regression menggunakan dua model yaitu minimum and maximum tair temperature.	The Tottori Prefecture is 3507 km2 in area and the population was 555,663 in October 2019. A total of 1108 cases were identified with 373 (33.7%) calls originating in the home (of these, 59.8%	In this study, it was found that only age was associated with the incidence of heatstroke in both models used. The group most at risk of heatstroke was in the age group of ≥65 years old due to a decline in cognitive and physiological function.

				were the age of 75).	
Deng et al. (2025)	Heatstroke characteristics and meteorological conditions in Hefei, China: thresholds and driving factors	China	Ecological study using correlation analysis, cluster analysis and linear regression analysis	The dataset contained 4629 heatstroke cases from all the hospitals in Hefei during 2008–2022, including detailed information on gender, age, time of heatstroke occur rence, and severity of the condition.	The growth rate of heatstroke was 0.8/0.7 case/ºC, 1.5/1.3 case/ºC, 2.0/1.7 case/ºC in the young, middle and old groups for T/Tmax. It was found that elderly people had the highest growth rate
Oh et al. (2024)	Heat wave exposure and increased heat-related hospitalizations in young children in South Korea: A time-series study	South Korea	A time-series study	Using the National Health Insurance Service (NHIS) database, which provides medical records from 2015 to 2019 in South Korea	16,879 daily heat-related hospitalizations among children younger than five years. The relative risk (RR) due to heat wave exposure within two days (lag2) (12 definitions: 70th to 90th percentile of maximum temperature) ranged from 1.038 (95% confidence interval (CI): 0.971, 1.110) to 1.083 (95% CI: 1.036, 1.133)

Almost all articles generally use ecological design studies. Previous studies emphasized the importance of addressing the issue of heatstroke and were mainly conducted in developed countries, such as the United States, Japan, and Canada. However, significant regional differences in the risk of heatstroke and adaptation measures existed due to differences in ethnicity, environment, and climate. Due to the low level of information integration in the past, there were no comprehensive data sources available for studying the risk of heatstroke in developing countries. In the era of high-speed informatization, big data provides us with the richness of data resources, and the new techniques allow us to analyze heatstroke in an interdisciplinary way (Chen et al., 2018).

3.2 Heatwave and outcomes

Ground meteorological conditions, including temperature, humidity, wind, cloud, and other factors, were considered in analyzing the occurrence of heatstroke. In addition, socioecological factors, such as vegetation cover, housing and work conditions, and gross domestic product (GDP), were also integrated as influencing factors of heatstroke (Wang et al., 2019) The incidence of heatstroke due to heatwaves often has different dynamics because the daily air temperature has varying numbers, as in Bai's study, the impact by age group is less consistent for three years. In 2011, the most affected group was those aged 0–15 years, while the middle-aged and elderly populations had a higher risk of experiencing heat-related conditions in 2012 and 2013 respectively (Bai et al., 2014) These findings indicate that the relationship between heatwaves and health outcomes is not uniform but varies across time and population groups. Differences in lag effects, temperature thresholds, and demographic characteristics suggest that heat-related risks are context-specific rather than universally consistent.

3.3 Age vulnerability

There are two types of heatstroke in terms of activity conditions, namely heatstroke due to physical activity and heatstroke due to non-physical activity, where high temperature is the main risk factor in both conditions. Usually, the incidence of heatstroke due to physical activity is not so severe because it occurs in the age group of children or adults due to exercise and work. Meanwhile, heatstroke due to non-physical activity occurs indoors caused by independent risk factors such as old age, living alone, and congenital diseases such as heart disease. Where this non-physical activity heatstroke incident occurs in old age (Japanese Association for Acute Medicine, 2015). Heatstroke is considered a fatal disease, generally characterized by unbalanced heat production and dissipation, due to exposure to a hot environment or strenuous sports activities, which is characterized by a body temperature of >400C and also accompanied by another organ dysfunction that can be life-threatening (Khan & Mubeen, 2025).

The discovery that needs to be underlined in this study is the fact that the incidence of heatstroke is more common in the elderly age group. This is caused by many factors, namely the physiological condition of the elderly body and congenital and chronic diseases. For example, skin blood flow is lower in old age and the redistribution of blood volume from retroperitoneal venous tissue to the cutaneous capillary bed decreases. Older people also sweat more slowly and less than younger people. As a result of these changes, less heat can be removed through the skin in elderly (Lee et al., 2016). Even the elderly who are only indoors also have the risk of experiencing heatstroke due to the increasingly hot earth temperature. Research mentioned that in old age, it is difficult for their bodies to release heat, thus causing a high risk of experiencing heatstroke due to a decrease in thermoregulation. The core temperature in elderly is higher compared to the control group of healthy young adults, thus leading to faster improvement and the appearance of early heatstroke symptoms (Ou et al., 2023). The explanation is that older adults have a disrupted sweating response, experiencing rapid increases in core temperature due to dehydration and psychological stress. During heat stress exposure, older adults have higher core temperatures and faster increases in core temperature (Howard & Krishna, 2022). This suggests that older adults are more sensitive to high temperatures during heat waves and experience heatstroke at "lower" levels of heat stress compared to healthy young adults (Khraishah et al., 2022).

Research by Jeremy et al. on the heatstroke incident among the elderly group also led to many deaths (Hess et al., 2014). Another study by Nishat et al stated that the elderly group most vulnerable to heatstroke incidence was in the age range of >70 years. The morning period was found to be riskier for the elderly than the patients as a whole, while the afternoon and evening seemed to have a higher percentage of heatstroke incidence for patients overall than the vulnerable group. However, both groups experienced heat-related illnesses more frequently during the day, particularly from 10 a.m. to 4 p.m. Vulnerable people aged 70 and over typically spend most of their time at home, resulting in the highest risk in residential areas for this group (Toosty et al., 2021) The average elderly experienced non-exertional heatstroke even though they do not turn on the AC due to their vulnerability to environmental exposure and temperatures below 30oC and it was also found that women are more susceptible to heatstroke than men especially if the temperature is 37oC or more (Khare et al., 2015). The higher prevalence of death in the ER among the elderly is likely due to physical weakness and underlying comorbid diseases. Research found that the elderly group easily experienced heatstroke due to a decrease in their body's cognitive and physiological function (Kondo et al., 2013; Leyk, 2019).

Although the elderly age group is more likely to experience heatstroke, the age group of children is at risk of experiencing it, as shown by the research of Kazutaka et al (Oka et al., 2023). This explains that heatstroke due to physical activity occurs more often outdoors with less severe cases. The incidence of heatstroke due to physical activity, which can occur in a short period of time, is high in the younger generation when exercising and the middle-aged generation while working. However, non-physical heatstroke occurs indoors and is caused by independent risk factors such as old age, living alone, and comorbidities (heart disease) (Japanese Association for Acute Medicine, 2015; Zeng et al., 2024). In line with research by Bai et al. (2014), the most affected groups were those aged 0–15 years, while the middle-aged and elderly populations were at higher risk of developing heat-related conditions in 2012 and 2013, respectively. However, all age groups are at risk. Meanwhile, a study by Jongmin et al stated that 16,879 daily heat-related hospitalizations among children under five years old (Oh et al., 2024). Children's vulnerability to high temperatures can potentially be explained by physiology, metabolic rate, cardiovascular response, behavioral, and self-care ability aspects (Xu et al., 2014). First, in terms of physiology, children have a greater body surface area-to-mass ratio than adults. Next, concerning metabolism, the greater metabolic rate in children than in adults likewise might cause them to be more sensitive to extreme temperatures (Kim et al., 2020). Obese children are less tolerant of heat than children of a normal weight (Hoffman et al., 2020). Third, in terms of cardiovascular responses, as the core body temperature increases, children have a lower cardiac output at a given metabolic rate than adults (Oh et al., 2024). Fourth, regarding behavior, children spend more time outdoors and participate in more vigorous activities than adults, which results in increased exposure to outdoor heat (Xu et al., 2014). Finally, in terms of self-care ability, children, especially neonates, infants, and children younger than one year, cannot take care of themselves and thus are dependent on others to protect them from unsafe environments (Baldwin et al., 2023; Layton et al., 2020).

3.4 Determinants of heatstroke vulnerability across contexts

The findings of this review indicate that vulnerability to heatstroke is shaped by a complex interaction of environmental, socio-economic, and health-related determinants, all of which vary across geographic and contextual settings. Rather than being uniform, the impact of heatwaves differs significantly depending on local climate conditions, population characteristics, and levels of adaptive capacity. This highlights that heatstroke risk is not solely a function of temperature exposure but is also mediated by broader contextual factors that influence (Oh et al., 2024). exposure and resilience. The impact of human-produced greenhouse gases on the earth is absolutely inevitable, as a result of climate change that has an impact on global warming, extreme weather, heavy rains, heatwaves and droughts (Arsad et al., 2022) It is estimated that rising global temperatures will result in premature deaths from heat around the world (Gasparrini et al., 2017). The elderly group is said to be more at risk of heatstroke as well as their physical susceptibility to high temperatures (Oka et al., 2023). As temperatures continue to rise at unprecedented levels, health impacts have increased and spread and claimed many lives in recent years. The annual death rate of heatstroke in individuals over the age of 65 has increased by 68% in the last 20 years and more than a third of deaths in the last 30 years have occurred due to climate change (Matsee et al., 2023).

From the reviewed article, the occurrence of heatstroke occurs in Japan, this is because Japan stretches from north to south, this country has a variety of climates. As a result, large regional variations in the incidence of heatstroke are expected to occur (Oka et al., 2023).

Japan is also the country with the largest elderly population in the world, the elderly often suffer from chronic diseases, such as cardiovascular, respiratory, and kidney diseases as well as diabetes, which can be affected by heat and are therefore a concern regarding the health impacts of climate change. Elderly individuals with low socioeconomic status are one of the most vulnerable groups to heat waves because they may lack adequate adaptive capacity (Kim et al., 2020). Although the most vulnerable group at risk of heatstroke is the elderly group, it does not mean that children are not a vulnerable group, children and the elderly are the risk groups for heatstroke, there were 52 children who died from heatstroke in the UK in 2018, where this number is predicted to increase in the next 30 years. Large body surface and increased heat per kilogram due to metabolic rate and less sweating are factors that make children susceptible to heatstroke. There are many scenarios that can cause children to be exposed to heat attacks such as children who are trapped in cars, babies who are close to the heater, and teenagers who play football on a hot day (Forsyth & Solan, 2020).

3.5 Health equity and policy implications

The findings of this review indicate that the burden of heatstroke is not evenly distributed across populations, with elderly individuals and children consistently identified as high-risk groups across the included studies. Evidence from multiple studies shows that elderly populations experience higher rates of heat-related morbidity and mortality, particularly in the presence of chronic conditions and reduced physiological capacity to cope with heat stress (Hess et al., 2014; Oka et al., 2023; Toosty et al., 2021). In parallel, children are also shown to be vulnerable, with increased heat-related hospitalizations observed during periods of elevated temperature, particularly among younger age groups (Oh et al., 2024). These findings suggest that age is a critical determinant of vulnerability in the context of heatwave exposure. Beyond age-related susceptibility, the reviewed studies also point to the role of environmental and contextual factors in shaping heat-related risks. For example, variations in temperature, humidity, and other meteorological conditions are associated with fluctuations in heatstroke incidence across different settings and time periods (Bai et al., 2014; Deng et al., 2025). In addition, several studies indicate that non-exertional heatstroke, particularly among elderly individuals, often occurs in indoor environments, suggesting that living conditions and prolonged exposure to heat may contribute significantly to risk (Toosty et al., 2021). These findings imply that vulnerability is influenced not only by external temperature but also by the immediate environment in which individuals reside. Although the included studies primarily focus on environmental and demographic determinants, they also provide indirect evidence that broader social and health-related factors may contribute to unequal risk. For instance, the higher incidence of severe outcomes among elderly individuals has been linked to the presence of comorbidities and reduced functional capacity (Hess et al., 2014; Oka et al., 2023). In addition, patterns such as increased risk among individuals in residential settings or those spending extended periods indoors suggest potential links to social isolation and living arrangements (Toosty et al., 2021). While these factors are not always explicitly analyzed in the included studies, they indicate that vulnerability to heatstroke may be shaped by a combination of physiological and contextual conditions.

These observed disparities highlight important implications for health equity. The concentration of heatstroke risk among specific population groups suggests that the impacts of heatwaves are experienced unevenly, even within the same geographic area. This uneven distribution of risk points to differences in exposure, sensitivity, and capacity to respond to extreme heat. While the included studies do not directly measure socio-economic inequality, their findings are consistent with broader evidence suggesting that limited adaptive capacity, whether due to age, health status, or living conditions, can increase susceptibility to heat-related illness. These patterns also reveal potential limitations in existing public health responses to heatwaves. Many interventions are designed at the population level and may not adequately account for differences in vulnerability among subgroups. For example, general heat warnings may not effectively reach or protect elderly individuals living alone or caregivers responsible for young children. The evidence from this review suggests that without targeted approaches, such interventions may have limited effectiveness in reducing risk among the most vulnerable populations.

In response to these challenges, several implications for public health policy and climate adaptation can be identified. An appropriate and effective public health response must address multiple components including local health services, social and cultural characteristics, and availability of human and financial resources to minimize the impact of extreme heat on the population. People with diabetes mellitus, cardiovascular, cerebrovascular, neurologic, mental, chronic kidney, and chronic obstructive pulmonary disease are at increased risk of disease exacerbation and death when exposed to extreme temperatures. Additionally, medications such as diuretics, neuroleptics, antipsychotics, tranquilizers, and anticholinergics reduce patients' tolerance to the heat; consequently, these patients are at higher risk of insufficient water intake, impaired thermoregulation, and death (Kravchenko et al., 2013). Therefore, it is very important for older adults to take effective measures to reduce the increase in core temperature and avoid heat-related illness or heatstroke during extreme weather. Prevention of classic heatstroke in older adults can be achieved in four ways: management of environmental conditions (e.g., using air conditioning), hydration (consuming fluids), heat acclimatization, reduction or no use of medications that partially alter thermoregulation, and the use of personal cooling systems (using electric fans, wearing cooling vests, etc.) (Hifumi et al., 2018).

While some of these policy implications extend beyond the direct findings of the included studies, they are supported by the observed patterns of vulnerability and are consistent with the broader literature on climate-related health risks. Overall, the results of this review suggest that effective responses to heatwaves require not only an understanding of biological susceptibility but also a recognition of the contextual and structural factors that shape vulnerability. Integrating these considerations into public health and climate policies will be critical for developing more targeted and equitable strategies to reduce heat-related health impacts. Due to the variety of study designs in the reviewed articles, the research cannot be continued to a more complex meta-analysis stage.

4. Conclusions

This study demonstrates that heatwave exposure is a significant public health concern, disproportionately affecting vulnerable populations, particularly the elderly and children. According to the included studies, elderly individuals consistently exhibit the highest risk of heatstroke due to a combination of physiological decline, comorbid conditions, and reduced capacity to adapt to extreme heat. Children, while less frequently associated with mortality, remain vulnerable due to physiological sensitivity and dependency on caregivers, highlighting the need for age-specific considerations in heat-health responses. Importantly, the findings of this review suggest that vulnerability to heatstroke is not solely determined by biological factors but is also shaped by environmental conditions and contextual factors such as living arrangements and patterns of exposure. This underscores the need to move beyond generalized approaches and adopt more targeted strategies that address the specific risks faced by different population groups.

From a policy perspective, several key implications emerge. Heatwave early warning systems should be strengthened and integrated into community-level health planning, ensuring that alerts are accessible and tailored to high-risk populations, including elderly individuals living alone and households with young children. Public health interventions should prioritize preventive measures, such as promoting hydration, reducing heat exposure, and improving awareness of early symptoms of heat-related illness through targeted education campaigns. Long-term climate adaptation strategies must address structural determinants of vulnerability, including improving housing conditions, expanding access to affordable cooling, and incorporating heat mitigation measures into urban planning. For practitioners, these findings highlight the importance of incorporating heat-related risk assessment into routine care, particularly for patients with chronic diseases and reduced thermoregulatory capacity. For researchers, this review identifies a critical gap in evidence from developing countries, indicating the need for more geographically diverse and context-specific studies to better understand heat-related health risks globally.

In conclusion, as climate change continues to intensify the frequency and severity of heatwaves, addressing heatstroke requires a comprehensive approach that integrates clinical, environmental, and social perspectives. Prioritizing vulnerable populations and embedding equity considerations into public health and climate policies will be essential to reducing the growing burden of heat-related illness in the future.

Acknowledgement
The authors gratefully acknowledge the support and contributions of all individuals and institutions that assisted in the completion of this research.

Author Contribution
F.H.H., designed the systematic review, developed the review protocol, conducted the literature search, performed data extraction, and drafted the manuscript. C.Z.P., screened articles for inclusion, contributed to the data synthesis, edited the manuscript for clarity and accuracy. Y.S., analyzed the quality of the studies included in the review, assisted with data analysis, provided methodological input. S.P.J., analyzed the quality of the studies included in the review, contributed to writing the results and discussion, and revised the manuscript.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The authors declare no conflict of interest.

Declaration of Generative AI Use
The authors declare no using AI.

Open Access
©2026. The authors. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original authors and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: http://creativecommons.org/licenses/by/4.0/

References

Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Norlen, M., Baharom, M., Osman, Y., Radi, M. F. M., & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: A systematic review. *International Journal of Environmental Research and Public Health*, *19*(23), 16356. https://doi.org/10.3390/ijerph192316356

Bai, L., Ding, G., Gu, S., Bi, P., Su, B., Qin, D., Xu, G., & Liu, Q. (2014). The effects of summer temperature and heat waves on heat-related illness in a coastal city of China, 2011-2013. *Environmental Research*, *132*, 212–219. https://doi.org/10.1016/j.envres.2014.04.002

Baldwin, J. W., Benmarhnia, T., Ebi, K. L., Jay, O., Lutsko, N. J., & Vanos, J. K. (2023). Humidity's role in heat-related health outcomes: a heated debate. *Environmental health perspectives*, *131*(5), 055001. https://doi.org/10.1289/EHP11807

Canel, L., Zisimopoulou, S., Besson, M., & Nendaz, M. (2016). Topiramate-induced severe heatstroke in an adult patient: A case report. *Journal of Medical Case Reports*, *10*(1). https://doi.org/10.1186/s13256-016-0835-5

Chen, R., Yin, P., Wang, L., Liu, C., Niu, Y., Wang, W., Jiang, Y., Liu, Y., Liu, J., Qi, J., You, J., Kan, H., & Zhou, M. (2018). Association between ambient temperature and mortality risk and burden: Time series study in 272 main Chinese cities. *BMJ (Online)*, *363*. https://doi.org/10.1136/bmj.k4306

Coates, L., Haynes, K., O'Brien, J., McAneney, J., & de Oliveira, F. D. (2014). Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844–2010. *Environmental Science & Policy*, *42*, 33–44. https://doi.org/10.1016/j.envsci.2014.05.003

Deng, X., Zhao, L., Xiao, C., Dai, R., Xu, Q., Yao, Y., Liang, C., Yao, L., & He, D. (2025). Heatstroke characteristics and meteorological conditions in Hefei, China: thresholds and driving factors. *BMC Public Health*, *25*(1). https://doi.org/10.1186/s12889-025-21577-y

Ferrer, R., & Iba, T. (2025). Molecular mechanisms of heatstroke: Pathophysiology and cell death pathways. *Juntendo Medical Journal*, *71*(5), 308–312. https://doi.org/10.14789/ejmj.JMJ25-0023-P

Forsyth, N., & Solan, T. (2022). It's getting hot in here: heat stroke in children and young people for paediatric clinicians. *Paediatrics and Child Health*, *32*(12), 471-475. https://doi.org/10.1016/j.paed.2022.10.004

Gasparrini, A., Guo, Y., Sera, F., Vicedo-Cabrera, A. M., Huber, V., Tong, S., de Sousa Zanotti Stagliorio Coelho, M., Nascimento Saldiva, P. H., Lavigne, E., Matus Correa, P., Valdes Ortega, N., Kan, H., Osorio, S., Kyselý, J., Urban, A., Jaakkola, J. J. K., Ryti, N. R. I., Pascal, M., Goodman, P. G., … Armstrong, B. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health*, *1*(9), e360–e367. https://doi.org/10.1016/S2542-5196(17)30156-0

Han, Q., Liu, Z., Jia, J., Anderson, B. T., Xu, W., & Shi, P. (2022). Web-based data to quantify meteorological and geographical effects on heat stroke: Case study in China. *GeoHealth*, *6*(8). https://doi.org/10.1029/2022GH000587

Hess, J. J., Saha, S., & Luber, G. (2014). Summertime acute heat illness in U.S. emergency departments from 2006 through 2010: Analysis of a nationally representative sample. *Environmental Health Perspectives*, *122*(11). https://doi.org/10.1289/ehp.1306796

Hifumi, T., Kondo, Y., Shimizu, K., & Miyake, Y. (2018). Heat stroke. In *Journal of Intensive Care* (Vol. 6, Number 1). BioMed Central Ltd. https://doi.org/10.1186/s40560-018-0298-4

Hoffman, J. S., Shandas, V., & Pendleton, N. (2020). The effects of historical housing policies on resident exposure to intra-urban heat: A study of 108 US Urban Areas. *Climate*, *8*(1), 12. https://doi.org/https://doi.org/10.3390/cli8010012

Howard, S., & Krishna, G. (2022). How hot weather kills: the rising public health dangers of extreme heat. *BMJ*, *378*, o1741. https://doi.org/10.1136/bmj.o1741

Japanese Association for Acute Medicine. (2015). *Heatstroke Treatment Guidelines*.

Kania, O. D., & Hess, D. B. (2025). Demand for and development of greenery in Historic Town Squares: The case of Zakliczyn. *Technical Transactions*, *122*(1). https://doi.org/10.37705/TechTrans/e2025004

Khan, A., & Mubeen, M. (2025). Heat stroke in the era of global warming: A call for urgent action. *Annals of Global Health*, *91*(1), 1. https://doi.org/10.5334/aogh.4519

Khare, S., Hajat, S., Kovats, S., Lefevre, C. E., De Bruin, W. B., Dessai, S., & Bone, A. (2015). Heat protection behaviour in the UK: Results of an online survey after the 2013 heatwave. *BMC Public Health*, *15*(1). https://doi.org/10.1186/s12889-015-2181-8

Khraishah, H., Alahmad, B., Ostergard, R. L., AlAshqar, A., Albaghdadi, M., Vellanki, N., Chowdhury, M. M., Al-Kindi, S. G., Zanobetti, A., Gasparrini, A., & Rajagopalan, S. (2022). Climate change and cardiovascular disease: implications for global health. *Nature Reviews Cardiology*, *19*(12), 798–812. https://doi.org/10.1038/s41569-022-00720-x

Kim, S., Kim, S. Y., Oh, J., Chae, Y., Park, J., Kim, D., & Kim, Y. M. (2020). Effects of the 2018 heat wave on health in the elderly: implications for adaptation strategies to climate change. *Environmental Analysis Health and Toxicology*, *35*(4). https://doi.org/10.5620/eaht.2020024

Kondo, M., Ono, M., Nakazawa, K., Kayaba, M., Minakuchi, E., Sugimoto, K., & Honda, Y. (2013). Population at high-risk of indoor heatstroke: The usage of cooling appliances among urban elderlies in Japan. *Environmental Health and Preventive Medicine*, *18*(3), 251–257. https://doi.org/10.1007/s12199-012-0313-7

Kravchenko, J., Abernethy, A. P., Fawzy, M., & Lyerly, H. K. (2013). Minimization of heatwave morbidity and mortality. *American journal of preventive medicine*, *44*(3), 274-282. https://doi.org/10.1016/j.amepre.2012.11.015

Layton, J. B., Li, W., Yuan, J., Gilman, J. P., Horton, D. B., & Setoguchi, S. (2020). Heatwaves, medications, and heat-related hospitalization in older Medicare beneficiaries with chronic conditions. *PloS one*, *15*(12), e0243665. https://doi.org/10.1371/journal.pone.0243665

Lee, J. H., Kim, Y. K., Kim, K. S., & Kim, S. (2016). Estimating clothing thermal insulation using an infrared camera. *Sensors (Switzerland)*, *16*(3). https://doi.org/10.3390/s16030341

Leyk, D. (2019). Health Risks and Interventions in Exertional Heat Stress. *Deutsches Ärzteblatt International*. https://doi.org/10.3238/arztebl.2019.0537

Li, T., Shi, W., Wang, G., & Jiang, Y. (2025). Prevalence and risk factors of frailty in older patients with coronary heart disease: A systematic review and meta-analysis. *Archives of Gerontology and Geriatrics*, *130*, 105721. https://doi.org/10.1016/j.archger.2024.105721

Matsee, W., Charoensakulchai, S., & Khatib, A. N. (2023). Heat-related illnesses are an increasing threat for travellers to hot climate destinations. In *Journal of Travel Medicine* (Vol. 30, Number 4). Oxford University Press. https://doi.org/10.1093/jtm/taad072

Morioka, T., Tamura, K., & Sato, T. (2025). Influence of the South Asian high and Western Pacific subtropical high pressure systems on the risk of heat stroke in Japan. *Atmosphere*, *16*(6). https://doi.org/10.3390/atmos16060693

Oh, J., Kim, E., Kwag, Y., An, H., Kim, H. S., Shah, S., Lee, J. H., & Ha, E. (2024). Heat wave exposure and increased heat-related hospitalizations in young children in South Korea: A time-series study. *Environmental Research*, *241*. https://doi.org/10.1016/j.envres.2023.117561

Oka, K., He, J., Honda, Y., & Hijioka, Y. (2025). Economic burden of ambulance transports for patients with heatstroke under climate change: comparison of the effects of gradual temperature increases and extreme heat events. *Environmental Research Communications*, *7*(4), 041009. https://doi.org/10.1088/2515-7620/adc907

Oka, K., Honda, Y., Hui Phung, V. L., & Hijioka, Y. (2023). Potential effect of heat adaptation on association between number of heatstroke patients transported by ambulance and wet bulb globe temperature in Japan. *Environmental Research*, *216*. https://doi.org/10.1016/j.envres.2022.114666

Otani, S., Funaki Ishizu, S., Masumoto, T., Amano, H., & Kurozawa, Y. (2021). The effect of minimum and maximum air temperatures in the summer on heat stroke in Japan: A time-stratified case-crossover study. *International Journal of Environmental Research and Public Health*, *18*(4), 1–12. https://doi.org/10.3390/ijerph18041632

Ou, Y., Wang, F., Zhao, J., & Deng, Q. (2023). Risk of heatstroke in healthy elderly during heatwaves: A thermoregulatory modeling study. *Building and Environment*, *237*. https://doi.org/10.1016/j.buildenv.2023.110324

Sato, T., Kusaka, H., & Hino, H. (2020). Quantitative assessment of the contribution of meteorological variables to the prediction of the number of heat stroke patients for Tokyo. *Scientific Online Letters on the Atmosphere*, *16*, 104–108. https://doi.org/10.2151/SOLA.2020-018

Schmeltz, M. T., Marcotullio, P. J., Himmelstein, D. U., Woolhandler, S., & Sembajwe, G. (2016). Outcomes of hospitalizations for common illnesses associated with a comorbid heat-related illness in the United States, 2001-2010. *Climatic Change*, *138*(3–4), 567–584. https://doi.org/10.1007/s10584-016-1747-5

Sharma, J., & Ravindranath, N. H. (2019). Applying IPCC 2014 framework for hazard-specific vulnerability assessment under climate change. *Environmental Research Communications*, *1*(5), 051004. https://doi.org/10.1088/2515-7620/ab24ed

Shu-Yuan, L., Jing-Chun, S., Han-Ding, M., Jin-Bao, Z., & Song, Q. (2020). Expert consensus on the diagnosis and treatment of heat stroke in China. *Military Medical Research*, *7*, 1–20. https://doi.org/10.1186/s40779-019-0229-2

Toloo, G. S., Yu, W., Aitken, P., FitzGerald, G., & Tong, S. (2014). The impact of heatwaves on emergency department visits in Brisbane, Australia: A time series study. *Critical Care*, *18*(2). https://doi.org/10.1186/cc13826

Toosty, N. T., Hagishima, A., & Tanaka, K. I. (2021). Heat health risk assessment analysing heatstroke patients in Fukuoka City, Japan. *PLoS ONE*, *16*(6 June). https://doi.org/10.1371/journal.pone.0253011

Wang, Y., Song, Q., Du, Y., Wang, J., Zhou, J., Du, Z., & Li, T. (2019). A random forest model to predict heatstroke occurrence for heatwave in China. *Science of The Total Environment*, *650*, 3048–3053. https://doi.org/10.1016/j.scitotenv.2018.09.369

Wijerathne, B. T. B., Pilapitiya, S. D., Vijitharan, V., Farah, M. M. F., Wimalasooriya, Y. V. M., & Siribaddana, S. H. (2016). Exertional heat stroke in a young military trainee: Is it preventable? *Military Medical Research*, *3*(1). https://doi.org/10.1186/s40779-016-0078-1

Wright, C. Y., Chersich, M., & Mathee, A. (2019). National health insurance and climate change: Planning for South Africa's future. *South African Journal of Science*, *115*(9/10), 24–26. https://doi.org/10.17159/sajs.2019/5800

Xu, Z., Sheffield, P. E., Su, H., Wang, X., Bi, Y., & Tong, S. (2014). The impact of heat waves on children's health: a systematic review. *International Journal of Biometeorology*, *58*(2), 239–247. https://doi.org/10.1007/s00484-013-0655-x

Yoeli, T., Negev, M., Paz, S., & Weinstein, G. (2025). Climate change, heat-related health risks, and stroke: Perceptions and adaptations among older israeli adults. *Climate*, *13*(4). https://doi.org/10.3390/cli13040076

Zeng, M., Baptista, E. A., & Kakinuma, K. (2024). Heat impacts on an aging society: a spatio-temporal analysis of heatstroke deaths in Japan. *Environmental Research Communications*, *6*(11), 115003. https://doi.org/10.1088/2515-7620/ad8990

Zhang, Y. (2024). *Association between T2DM and subsequent cardiovascular events*.

Zhang, Z., Wu, X., Zou, Z., Shen, M., Liu, Q., Zhangsun, Z., Zhao, H., Lei, W., Wang, Z., Dong, Y., & Yang, Y. (2024). Heat stroke: Pathogenesis, diagnosis, and current treatment. In *Ageing Research Reviews* (Vol. 100). Elsevier Ireland Ltd. https://doi.org/10.1016/j.arr.2024.102409

Zhao, Q., Guo, Y., Ye, T., Gasparrini, A., Tong, S., Overcenco, A., ... & Li, S. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. *The Lancet Planetary Health*, *5*(7), e415-e425. https://doi.org/10.1016/S2542-5196(21)00081-4

Biographies of Authors

Fadilah Habibull Hamda, Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia

- Email: habibulhamdafadilah@gmail.com
- ORCID: 0009-0000-2354-9125
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Citta Zahra Primalia, Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia;

- Email: primalia.citta@gmail.com
- ORCID: 0009-0002-5848-9526
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Yolanda Safitri, Department of Health Education and Behavioral Science, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia.

- Email: yolandasafitri23@gmail.com
- ORCID: 0009-0001-5722-0931
- Web of Science ResearcherID: N/A
- Scopus Author ID: 58630868800
- Homepage: https://scholar.google.com/citations?user=TyzjGz8AAAAJ&hl=id

Soraya Permata Sujana, Department of Environmental Health of Epidemiology, Faculty of Public Health, Universitas Indonesia, Depok, West Java 16424, Indonesia.

- Email: sorayapermatasujana@gmail.com
- ORCID: 0009-0004-3433-1032
- Web of Science ResearcherID: N/A
- Scopus Author ID: 59412684200
- Homepage: https://scholar.google.com/citations?user=NEZ_89sAAAAJ&hl=id