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Review

Impact of extreme heat and heatwaves on children's health: A scoping review

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ABSTRACT

Introduction: Due to climate change, the frequency of heatwaves and extreme heat events (EHE) has increased over the last five decades and is expected to continue increasing.
Methods: In this scoping review, we searched the literature for how EHEs and heatwaves impact pediatric health and how children can adapt to these threats. We used the PRISMA Extension for Scoping Reviews framework and searched several databases for studies pertaining to pediatric health, heatwaves, and EHEs.
Results: The search generated 1719 studies that were screened by the authors. Ultimately, 113 studies were included in this review. We found that extreme heat exposure leads to a variety of adverse health outcomes in pediatric patients; some of the most notable are increased risks of adverse birth outcomes, including preterm birth and low birth weight. Extreme heat exposure was also associated with increased rates among children of emergency department visits, asthma exacerbations, heat illness, and impaired school performance.
Conclusion: Children will continue to face the repercussions of extreme heat as global temperatures continue to rise. It is imperative that future research includes adaptation measures to help keep children healthy and safe during periods of extreme heat.

1. Introduction

The frequency of extreme heat events (EHEs) has increased over the last five decades, largely due to anthropogenic climate change. In the United States (U.S.), the average number of heatwaves across 50 cities has climbed from two per year in 1961 to six per year in 2021 [1]. The length of heatwave season has also increased by an average of 49 days during the same period [1]. This growth in extreme heat is mirrored elsewhere around the world. Between 2000 and 2016, an additional 125 million people were exposed to heatwaves [2]. Consensus among climate scientists attributes the increased frequency and intensity of heatwaves to human-generated greenhouse gas emissions [3]. Children will bear an increased burden of extreme heat compared with their parents and grandparents. The United Nations Children's Fund (UNICEF) estimates that 559 million children are already being exposed to high heatwave frequency [4]. By 2050, this number is expected to rise to 2 billion, encompassing the majority of children on the planet [4].

Climate change detrimentally affects children's health in a myriad of ways. Rising global temperatures have led to shifts in infectious disease patterns, longer allergy seasons, increased severity of respiratory illnesses, more frequent and intense natural disasters, higher rates of malnutrition, and poor mental health outcomes [5]. Although increasing global heat is an underlying factor for many of the downstream effects of climate change, this scoping review focuses specifically on the impacts of heatwaves and extreme heat events on pediatric health. Due to their unique physiology, growth, and development, infants and children suffer distinct consequences of extreme heat as compared to adults [5]. It is vital to assess current strategies to mitigate the health effects of extreme heat. This scoping review aims to assess what has been published over the past decade regarding the impacts of heatwaves and EHEs on pediatric health, including opportunities for adaptation and mitigation.

Abbreviations: BMI, body mass index; CO, carbon monoxide; ED, emergency department; EHE, Extreme heat event; EHI, exertional heat illness; EHS, exertional heat stroke; GDP, gross domestic product; LBW, low birth weight; NO2, nitrogen dioxide; PROM, premature rupture of membranes; PTB, preterm birth; SES, socioeconomic status; U.S., United States.

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2. Methods

In 2014, Xu Z, et al. published a systematic review on the impact of heatwaves on pediatric health outcomes; to provide an updated exploration of this topic, we only focused on studies with data collected in the past 10 years (2013 through 2023) [6]. To capture the diverse range of studies regarding this topic and to find opportunities for future research, we conducted a scoping review with search methods generated using guidance from the JBI PRISMA Extension for Scoping Reviews, as outlined by Tricco, et al. [7] In addition to our 2013−2023 data collection range, inclusion criteria were: studies that addressed the health impacts of extreme heat events related to climate change; empirical studies, reviews, editorials, commentaries, and opinion papers; studies published in English; and studies concerning a pediatric population or sub-population (age <18 years). Studies were excluded if they did not specifically address EHEs or heatwaves. Studies were also excluded if they did not specifically mention children (age <18 years) or if all data was collected prior to 2013.

The search strategy was designed to find published and unpublished sources. The databases searched included Medline (Ovid), APA PsycInfo (Ovid), CINAHL with Full Text (EBSCO), and Scopus (Elsevier). Google Scholar was utilized to capture additional relevant literature beyond the traditional databases. A limited search of Dissertations & Theses Global with subsequent citation search (Proquest) was also undertaken. All references were uploaded into Covidence software, which then removed duplicates. All database searches were run during the second week of June 2023. Searches were limited to 2013-2023 and English language. Exclusion and inclusion criteria regarding the effects of extreme heat on children were applied to all references within Covidence. The full search strategy can be accessed in Supplementary Materials Table S1.

Title and abstract screening were completed by LS, HM, MM, and MN. Each reference was screened by two reviewers. If there was conflict between two reviewers, a third reviewer resolved the conflict. Full text review was completed by the same reviewers in the same method. Data extraction was then completed by LS, HM, MM, MN, and MC. Each study was extracted by one author. Extraction parameters were determined by group consensus among authors and modeled on previously published scoping reviews of similar topics. During data extraction, 15 studies were sent back to full text review due to concerns about meeting inclusion or exclusion criteria; those studies were then re-reviewed by two authors.

3. Results

3.1. Study Attributes

The initial search generated 2501 studies, from which 782 duplicates were removed. Thus, 1719 studies were screened in the title and abstract phase. Of the 430 studies assessed in full text review, 317 were excluded. Most exclusions were due to lack of a pediatric population, lack of specificity for heatwaves or EHEs, or lack of data collected after 2012. Ultimately, 113 studies met criteria to be included in the review (Fig. 1, Supplementary Materials Table S2).

The studies included in our review ranged in design. The most common study design was cohort (n=24), followed by cross sectional (n=17), narrative review (n=12), and text and opinion (n=11). There was only one randomized control trial.

The extracted articles geographically represented six continents. Thirty-three studies came from North America, the highest number of any continent. There were 22 studies from Asia, 15 from Australia, 13 from Europe, 6 from Africa, and 3 from South America. Twenty-one studies were global or presented data from multiple countries. Only a minority of the included studies focused solely on children; however, all of the included studies concerned children in at least some capacity. From the 113 studies that were extracted, multiple themes emerged regarding the impact of heatwaves and EHEs on pediatric health.

3.2. Themes

3.2.1. Neonatal Outcomes

Twenty-six papers discussed the impacts of extreme heat exposure or heatwaves on birth outcomes and neonatal health. Consistent with prior reviews [8], most studies that met our inclusion criteria found associations between EHE during pregnancy and adverse birth outcomes such as preterm birth (PTB), stillbirth, low birth weight (LBW), and premature rupture of membranes (PROM). One systematic review of 68 studies and over 32 million births found that extreme heat exposure increased the risk of PTB by 16% and the risk of LBW by 31% [9]. There appears to be a period during late gestation in which the risks of heat-induced early delivery are greatest. Studies from China [10,11], the U.S. [12,13], and low-to-middle income countries [14] all found that the risk of PTB increased in association with heatwave or EHEs during the final week of gestation. Bekkar, et al. found that the risk of stillbirth increased 6% for each 1°C temperature increase during the week before deliveries in warm seasons [9].

Although the week leading up to delivery seems to be an especially vulnerable timeframe, the risk of heat-related PTB is not limited to this narrow window of gestation. Additional studies reported that extreme heat exposure during the first and second trimesters was also associated with increased risk of PTB [11,15]. The societal impacts of this phenomenon are sizable; an estimated 13,262 annual PTBs in China were attributed to heatwave exposure in utero, ultimately costing the healthcare system over $1 billion in added expenses [16].

Multiple studies reported associations between heat exposure and decreased birth weight or LBW [8,9]. There are a variety of other adverse birth outcomes that have been examined in the context of heat exposure, but to a lesser extent. One study found that EHE exposure during the final week of gestation was associated with increased risk of PROM and that women who suffered PROM were more likely to have been exposed to a heatwave as compared to pregnant women who did not suffer PROM [17]. Two studies suggested associations between congenital heart disease and EHEs within the first 8 weeks of gestation [18,19], but another study only found significant associations in later gestational windows [20].

The risks of extreme heat on pregnant women and their newborns are not equally distributed among all populations. Chersich's systematic review found that associations between heat and adverse birth outcomes were most pronounced in mothers with low socioeconomic status (SES) [21]. Similarly, the deleterious effect of EHE on PTB was somewhat mitigated in Chinese municipalities with higher gross domestic product (GDP) per capita [22]. Protection against EHE-induced LBW (up to 0.34 standard deviations) was seen among infants born to college-educated mothers in Guangzhou, China [23]. U.S. studies observed that Hispanic and non-Hispanic Black women were most vulnerable to experiencing extreme temperatures during pregnancy [24,25].

3.2.2. Emergency Department Attendance and Hospitalizations

Twenty-two references explored the relationship between heatwaves and emergency department (ED) visits or hospitalizations. Eight (36%) of those were from Australia and seven (32%) were from the United States. One U.S. study that analyzed warm season ED visits to children's hospitals found that EHE exposure was associated with an increased relative risk of 1.17 (95% CI: 1.12, 1.21) for all-cause ED presentations and significant risk increases for conditions such as dehydration, electrolyte disorders, and bacterial enteritis [26]. Similarly, a Canadian study on pediatric ED visits during warm season found a 22% increase in all-cause visits during extreme heat [27].

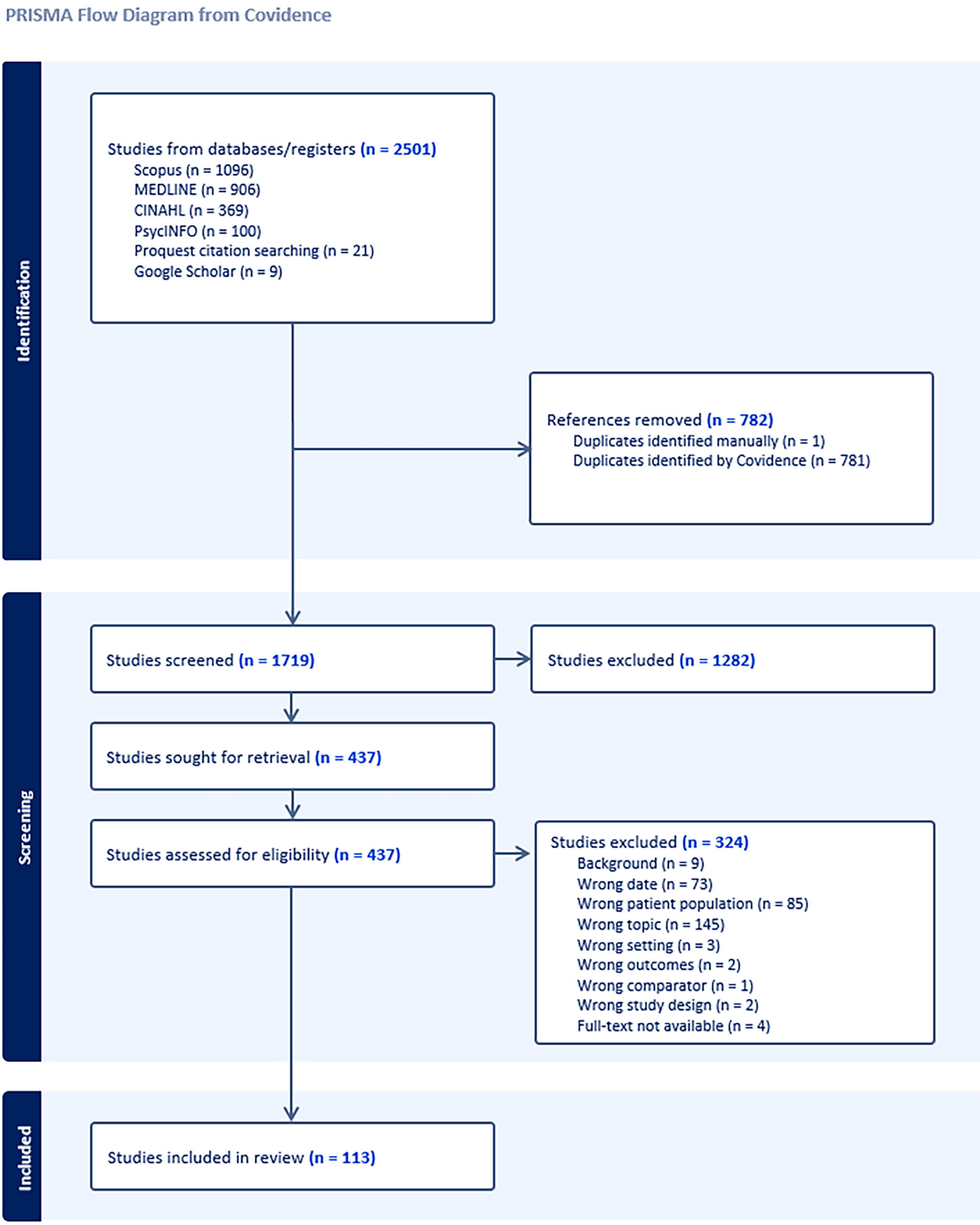

Fig. 1. Study Selection Flow Diagram

Overall, studies that looked specifically at pediatric ED visits found that EHEs were associated with increased utilization of the ED [26,27,28,29].

Socioeconomically disadvantaged populations were found to utilize health services at higher rates during heatwaves and periods of extreme heat. Dring, et al. found that patients in the lowest income quartile experienced more heat-related ED visits compared to patients in higher income quartiles [30]. Similarly, a team from Brazil found stronger associations between EHE and heat-related hospitalizations in cities with lower average household incomes and GDP per capita [31].

In some pediatric sub-populations and circumstances, hospitalization rates seem to be impacted by heatwaves and periods of extreme heat. For heatwaves reaching the 97th percentile of mean temperature in Brisbane, Australia, there was an observed increase in relative risk of infant hospitalization to 1.18 (95% CI: 1.05, 1.32) [32]. However, there was no significant risk increase during heatwaves at the 90th or 95th percentile of average temperature. Among patients with diabetes in Brisbane, pediatric subgroups had increased rates of hospitalization during low-intensity (RR 1.36; 95% CI: 1.04, 1.78), moderate-intensity (RR 1.49; 95% CI: 1.01, 2.20), and high-intensity heatwaves (RR 1.51; 95% CI: 1.08, 2.60) [33]. However, a separate study from Japan found no significant associations between EHE and pediatric (age 0-14 years) hospitalization rates for diabetic complications [34].

3.2.3. Morbidity and Mortality

The eleven studies that focused on morbidity and mortality covered a wide breadth of geography, including Peru, Turkey, Korea, Australia, India, the U.S., England, and multiple countries from Africa. There were mixed results regarding the relationship between heatwaves and pediatric mortality. A 2019 study from Varanasi, India found that children aged 0-4 years were the most vulnerable age group in terms of increased relative risk of all-cause mortality in association with heatwaves [35]. Another study from Istanbul that examined excess mortality attributable to heatwaves between 2013 and 2017 did not find a significantly increased risk of death in children aged 0-14 years. Rather, risk of death in persons aged ≥ 75 years increased during heatwaves [36].

Studies focused on morbidity did reveal an association between heatwaves and adverse pediatric outcomes. One such study from England found that, although heat illness presentations to primary care settings increased across all age groups during the 2013 summer heat wave, school-aged children (5-14 years) and the elderly were most affected, with children presenting to care earlier than older patients [37]. Overall, this group of studies found that heatwaves adversely impact pediatric morbidity and may sometimes increase mortality rates in children.

3.2.4. Respiratory Illness

Two papers in this review found an association between heatwaves and asthma exacerbations in children. The papers, both from China, found that cold spells were associated with worse asthma outcomes, but that heatwaves had detrimental effects as well [38,39]. Longer and more extreme heat waves had a greater impact on asthma admissions. A third study, a literature review, looked at the combined effects of poor air quality and heatwaves on respiratory illness. The authors found that incremental changes in PM2.5, PM10, ozone, CO, and NO_2 concentrations during heatwaves were associated with increased health care use in patients with underlying respiratory diseases [40].

3.2.5. Outdoor Activity and Injuries

The impacts of heatwaves and extreme heat on outdoor activities, sports, and injuries were discussed in eleven articles. Two studies specifically examined the impact of extreme heat on farm workers, including children. One study from North Carolina conducted in-depth survey interviews with 165 Latinx children aged 10-17 working on farms, of which 34 were aged 10-13 years [41]. The surveys found that heat-related illness is common in this population. The most frequently experienced symptoms were dizziness, headaches, and near syncope. Children reported that water break flexibility and early dismissal varied among their supervisors, due to a lack of formal work-place protections.

Four studies, all from the U.S., examined the relationships between heatwaves and athletes. Exertional heat illness (EHI) is estimated to occur in 9000 student athletes annually [42]; severe exertional heat stroke (EHS) is one of the leading causes of sudden death in athletes [43]. Two similar studies surveyed athletic trainers regarding heat acclimatization practices and preparedness for EHI. They found that 27.5% of surveyed schools use all 6 EHS-preparedness strategies. Schools in U.S. states with mandates had higher prevalence, but they only used all 6 strategies 52.9% of the time, showing an opportunity to optimize preparedness [44,45].

A study from Texas found that once temperatures exceeded 33°C, children aged 8-10 years spent more time under shade than in rigorous physical activity during school recess. The study showed that children on playgrounds with more trees and shade spent more time being physically active, which led authors to suggest a “Green Schoolyards Project” that includes planting more trees in these areas and scheduling recess during the cooler part of the day [46].

One study reviewed the impact of heat on unintentional injuries across high-income countries, while another study examined the impact of compound hot extremes by reviewing injury death data and meteorological data from provinces in China. They found that both unintentional injuries and injury-related death increased with heatwaves, although elderly populations were more affected than children [47,48].

3.2.6. School Performance

Two studies assessed student perceptions of thermal comfort and heat-related symptoms in the classroom. In a cross-sectional study from South Africa, 252 high school students from 8 schools completed an hourly heat health symptom log for 5 days during the summer months [49]. The majority of students reported at least one heat-related symptom, with fatigue and low concentration being the most common. Temperatures above 32°C were strongly associated with students feeling “tired” and finding it “hard to breathe.” Since warmer indoor temperatures were reported in classrooms made with asbestos sheeting and metal roofs, the authors suggested that classrooms be constructed from brick, when possible. They also recommended access to drinking water throughout the day and optimization of ventilation via open windows and fans.

A study by Golshan, et al. of students in multiple countries during the warm and cold seasons found that students experienced more thermal discomfort during the cold season [50]. The only heatwave that occurred during the study period was in Tel Aviv; 37% of students indicated their indoor thermal feeling as comfortable, and many actually felt cool due to air conditioning. Findings from these two studies suggest that air conditioning can mitigate the negative impacts of extreme heat on student comfort and performance at school Fig. 2.

3.2.7. Infectious Diseases

Several studies found associations between EHEs and an increased burden of infectious diseases. Two studies described increased *Vibrio* infections during heatwaves in Northern Europe in the 2010s. One group explored a cluster of infections in Sweden and Finland in 2014—a record-high 89 cases of *Vibrio* infections during a record-setting heat wave in Scandinavia. They reported 37% of cases were ear infections, and *Vibrio* was isolated from blood in 19% of cases [51]. The other group studying *Vibrio* examined a rise in infections in Germany

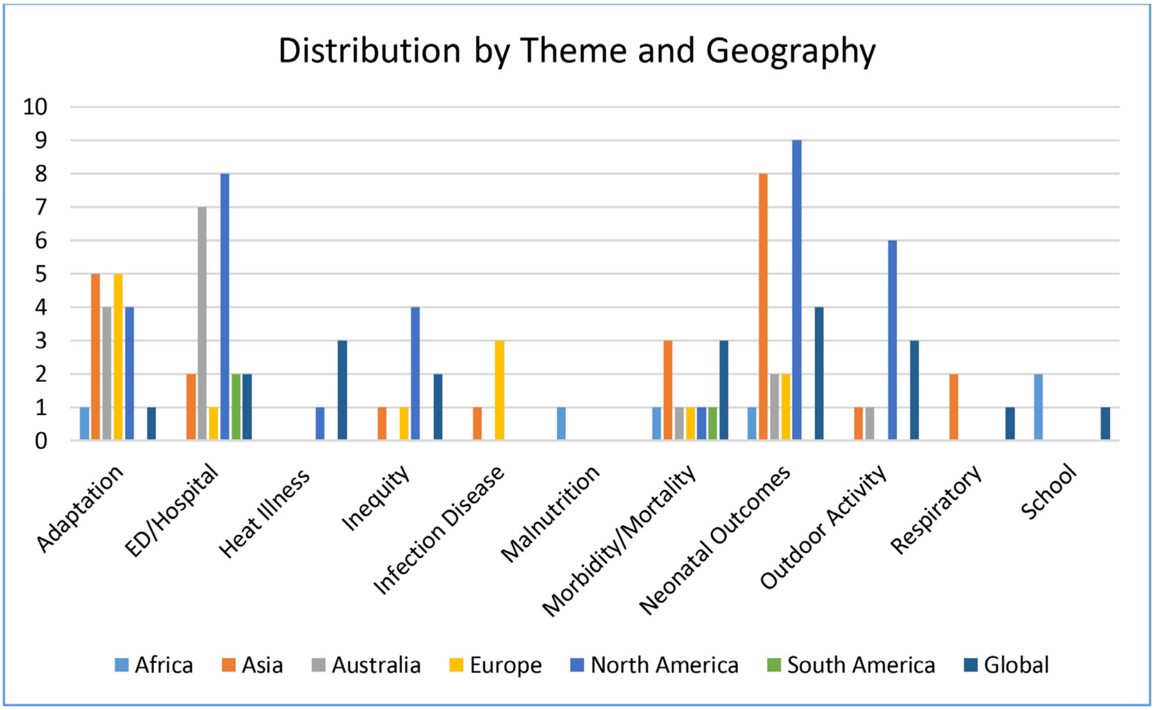

Fig. 2. Studies included in scoping review, organized by theme and continent

in the summers of 2018 and 2019. This group reported ear infections (25%) and a large proportion of wound infections (60%), from which about half of subjects developed septicemia [52]. Both studies suggested that the increase in *Vibrio* infections was related to exposure to water with increased surface temperatures during recreational activities. In both studies, children as young as 2-3 years old were affected by *Vibrio* infections [51,52].

One study found a positive relationship between the magnitude, duration, amplitude, and number of heatwaves and the incidence of Shiga toxin-producing *Escherichia coli* (STEC) infections in several regions in Italy [53]. A study from China suggested that extreme heat increased the risk and disease burden in children of bacillary dysentery caused by *Shigella* [54].

3.2.8. Malnutrition

Only one article assessed the impact of extreme heat on malnutrition in children. Block et al. studied the effect of extreme heat on maize growth in Tanzania and whether differences in crop yields were associated with changes in childhood growth [55]. Each day with temperatures greater than 29°C reduced predicted maize yields by 1% and in-utero exposure to crop growing days greater than 29°C was associated with decreased childhood growth in boys aged 0-5 years, but not girls. To determine whether this association was attributable to maternal nutritional deficiencies rather than in-utero exposure to extreme heat, the authors explored the relationship between maternal body mass index (BMI) and maize yields. They reported a strong, positive relationship between the BMI of women of childbearing age and maize yields from each growing season. The many confounding variables of this study's design make it difficult to imply causation between extreme heat and childhood malnutrition.

3.2.9. Adaptation

There were twenty studies that explored adaption or public concern in relation to heatwaves or EHEs. Spanning five continents, the geographical diversity of these studies highlighted the variety of settings in which adaptation strategies may be effective, such as schools and pediatrician offices. They also investigated the public response to adaptation strategies.

One study from China looked at the efficacy of school-based health education on extreme heat by comparing pre- and post-intervention surveys [56]. The knowledge, attitudes, and practices of both students and their parents increased after the educational intervention, with older students generating higher score changes than younger students. Another study examined the public perception of heat adaptation measures in Australian schools by collecting a sample of public comments that were posted on a news article about a proposed national heat protection policy [57]. The authors concluded that supporters of the plan wanted protection from extreme heat by utilizing modern technology; however, critics were concerned about over-regulation and air conditioning costs. Another article suggested anticipatory guidance related to extreme heat that pediatricians could share with patients. Recommendations included, "1. Keep kids cool, in the shade, rest often and avoid strenuous exercise. 2. Stay out of the sun, cover up, or use sunscreen. 3. Ensure good hydration [58]."

Community warning systems emerged as commonly reported adaptation strategies. One article examined the impact of a heatwave warning program on morbidity (ambulance use and ED presentations) and mortality in Adelaide, Australia. The local warning system was directed to high-risk populations and also included preventative measures. The authors found that the heatwave warning system helped decrease ambulance call-outs and ED presentations, but not mortality [59].

3.2.10. Geographic and Socioeconomic Inequity

The adverse effects of extreme heat are experienced inequitably by different children. While many articles in the review touched on this, eight studies focused specifically on the topic of inequity, four of which were from the U.S. These studies demonstrated that children living in families with lower SES experience a larger burden of adverse health effects due to heatwaves. Children of color were found to have higher risks than White children of ED visits, LBW, and PTB due to heatwaves [60]. One study found that children born to Black women with college degrees experience a higher relative risk of heatwave-related PTB compared to White women with college degrees [61]. A study from Bangladesh found that girls over age 11 years were more likely to be married the year of, or the year after, a moderate-to-severe heatwave as compared to years without heatwaves. The number of girls married increased with length of heatwaves [62].

There also appears to be inequity between children and older generations in how they experience extreme heat. This intergenerational injustice is quantified by Thiery, et al. in their birth cohort analysis [63]. They estimated that a person born in 1960 will experience an average of four heatwaves in their lifetime, while someone born in 2020 is expected to live through thirty heatwaves. This estimation did not take into account possible compounding factors, such as increased pollution, which could increase the frequency of heatwaves.

4. Discussion

This scoping review presents a comprehensive update on the global literature over the past decade regarding the impacts of heatwaves and extreme heat on pediatric health. In alignment with a recent review by Uibel D, et al. on ambient extreme heat and pediatric morbidity, we found that children are uniquely vulnerable to extreme heat due to their physiology and ongoing development [64]. While Uibel et al. studied the effects of ambient heat on urban U.S. populations, our study evaluated the impacts of heatwaves and EHEs, not ambient temperatures, on a more global scale. We also included adaptation strategies in our review.

The most robust evidence gleaned from our review pertains to neonates, where studies consistently demonstrate significant associations between extreme heat and adverse birth outcomes such as PTB, stillbirth, and LBW. We also found compelling evidence that during periods of extreme heat, children are more likely to visit the ED and are particularly susceptible to heat-related illnesses, asthma exacerbations, increased incidence of certain infectious diseases, and decreased concentration in educational settings. Throughout the literature, inequity was reported; children of color and children living in poverty were shown to experience worse health outcomes during heatwaves and EHEs.

To mitigate these risks, adaptation strategies are crucial. Recommendations include creating greener play spaces with denser tree canopy, mandating acclimatization protocols for sports teams, introducing heat warning systems, and providing anticipatory guidance. Given the impact of heat on learning, classroom-level heat adaptation strategies are increasingly important [49,50,56]. In regions without air-conditioning, adjusting the structure of the school building itself can reduce heat-related symptoms amongst students [49]. In the clinic, physicians should counsel patients and their families on how to identify symptoms of heat-related illness, ensure adequate hydration, and access cooling mechanisms and environments during heat events. Fortunately, there are a growing number of frameworks [65] and resources [66] that can help clinicians counsel their patients. For example, in A Pediatrician's Guide to Climate Change-Informed Primary Care, Philipsborn et al. recommend that pediatricians incorporate climate change into the normal flow of a primary care visit. For heat, this would include screening for utility insecurity (lack of air conditioning), promoting healthy exercise and activity at cooler hours and in shadier areas, anticipating possible heat illness in certain situations such as athletic events, and preparing parents to avoid dangerous consequences of a heatwave [65]. Beyond the clinic, health care providers have been called to action to advocate through policy and through community partnerships - representing the health perspective when it comes to extreme heat and child health [65].

Despite the valuable insights gained from our review, certain limitations must be acknowledged. While we attempted to ascertain a global view of the literature, our search was confined to English-language publications, which potentially excluded relevant studies published in other languages. Additionally, grey literature was not systematically evaluated. Finally, due to the wide range of study designs included in this review, we did not critically appraise the evidence within the included articles.

The most notable gaps in the literature are studies with pediatric-specific populations, studies from the Global South, and those with rigorous evaluations of adaptation strategies. Only 32% of the articles in this review focused specifically on pediatric populations; there is no shortage of opportunity to center children in future research. Additionally, the vast majority of studies were from the Global North, even though the Global South is currently projected to suffer more from the consequences of extreme heat. We recommend an intentional plan to support research from these regions. Many of the papers studied young children and neonates, but few studies focused on adolescents, a demographic deserving increased attention. Finally, the exciting adaptation strategies presented would benefit from further evaluations of efficacy. By understanding vulnerable populations and community resources, public health systems can prioritize efforts to protect communities in the wake of extreme heat caused by climate change.

Children will continue to face the repercussions of extreme heat as global temperatures rise. It is imperative that future research includes adaptation measures to safeguard children's health and well-being during periods of extreme heat.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Laura H Schapiro: Writing – original draft, Data curation, Conceptualization. **Mark A McShane:** Writing – original draft, Data curation, Conceptualization. **Harleen K Marwah:** Writing – original draft, Data curation, Conceptualization. **Megan E Callaghan:** Writing – original draft, Data curation. **Mandy L Neudecker:** Methodology, Data curation, Conceptualization.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.joclim.2024.100335.

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