Climate change and child health: a scoping review and an expanded conceptual framework

Daniel Helldén, Camilla Andersson, Maria Nilsson, Kristie L Ebi, Peter Friberg, Tobias Alfvén

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Department of Global Public Health, Karolinska Institutet, Stockholm, Sweden (D Helldén MD, T Alfvén PhD); **Department of Epidemiology and Global Health, Umeå University, Umeå, Sweden** (C Andersson MSc, Prof M Nilsson PhD); **Department of Global Health, School of Public Health, University of Washington, Seattle, WA, USA** (Prof K L Ebi PhD); **Swedish Institute for Global Health Transformation, Royal Swedish Academy of Sciences, Stockholm, Sweden** (Prof P Friberg PhD); **Department of Public Health and Community Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden** (Prof P Friberg); **Sachs' Children and Youth Hospital, Stockholm, Sweden** (T Alfvén)

Correspondence to: Mr Daniel Helldén, Department of Global Public Health, Karolinska Institutet, Stockholm 17177, Sweden **daniel.hellden@ki.se**

Climate change can have detrimental effects on child health and wellbeing. Despite the imperative for a fuller understanding of how climate change affects child health and wellbeing, a systematic approach and focus solely on children (aged <18 years) has been lacking. In this Scoping Review, we did a literature search on the impacts of climate change on child health from January, 2000, to June, 2019. The included studies explicitly linked an alteration of an exposure to a risk factor for child health to climate change or climate variability. In total, 2970 original articles, reviews, and other documents were identified, of which 371 were analysed. Employing an expanded framework, our analysis showed that the effects of climate change on child health act through direct and indirect pathways, with implications for determinants of child health as well as morbidity and mortality from a range of diseases. This understanding can be further enhanced by using a broader range of research methods, studying overlooked populations and geographical regions, investigating the costs and benefits of mitigation and adaptation for child health, and considering the position of climate change and child health within the UN Sustainable Development Goals. Present and future generations of children bear and will continue to bear an unacceptably high disease burden from climate change.

Introduction

The current impacts and future risks of climate change caused by human activities far surpass those of any other force that has transformed Earth's environment in recent history.[1] Although long-term magnitude and patterns of climate change are uncertain, projections suggest an increase of 2°C or more in the global average temperature could be realised by the end of this century, leading to crucial changes in Earth's geosphere, biosphere, cryosphere, hydrosphere, and atmosphere, with severe implications for human and planetary health.[2,3] Indeed, climate change will impact the health of children born today throughout their lifetime.[4]

Through its far reaching impact on all parts of society,[5] climate change will challenge the very essence of children's rights to survival, good health, wellbeing, education, and nutrition[6] as enshrined by the Convention on the Rights of the Child[7] and emphasised in the UN Sustainable Development Goals.[8] Climate change threatens to exaggerate the vulnerabilities of children and other populations at risk and could substantially hamper future progress and possibly even reverse the improvements made in child survival and wellbeing during recent decades.[6,9]

Despite the clear implications of climate change on child health, Sheffield and Landrigan[10] noted in their 2011 review that there were strikingly few studies examining the possible pathways and mechanisms within this area. The past few years have seen an accelerated momentum for studying the health effects of climate change.[11,12] Importantly, a comprehensive understanding of how children's health could be affected by climate change, as well as changes in weather patterns and their short and long term impacts, and an identification of strengths, weaknesses, and gaps in the literature to guide future research, policy, and practice are urgently needed. In response to this challenge, we did a Scoping Review to assess how climate change affects child health and wellbeing.

Methods

Search strategy and selection criteria

Due to the complex nature of the topic and the wide range of studies addressing it, a Scoping Review method was selected[13,14] based on a predetermined protocol in accordance with established principles (PRISMA Extension for Scoping Reviews)[15] In line with this protocol, a search strategy was developed, and the literature search was done on PubMed, Web of Science, Cochrane Library, Global Health, and WHO regional databases combining two broad blocks of search terms: children ("child", or "infant", or "adolescent") and climate change ("climate change", "global warming", "greenhouse effect", and "climate adaptation" in Medical Subject Heading [MeSH] terms and free text). The decision to not include specific search terms for weather variables (such as temperature) was made because the primary aim of the Scoping Review was to focus on a broad perspective of suggested climate change impacts on child health and not specific variables. Only English language

Key messages

- There is a growing body of research showing that climate change acts through multiple pathways to negatively affect child health and wellbeing
- Despite the imperative for a fuller understanding of how climate change interacts with different determinants to affect child health and wellbeing, gaps persist
- A range of research methods are needed to further understanding of vulnerable subpopulations and geographical regions, and of the costs and benefits of mitigation and adaptation for addressing risks

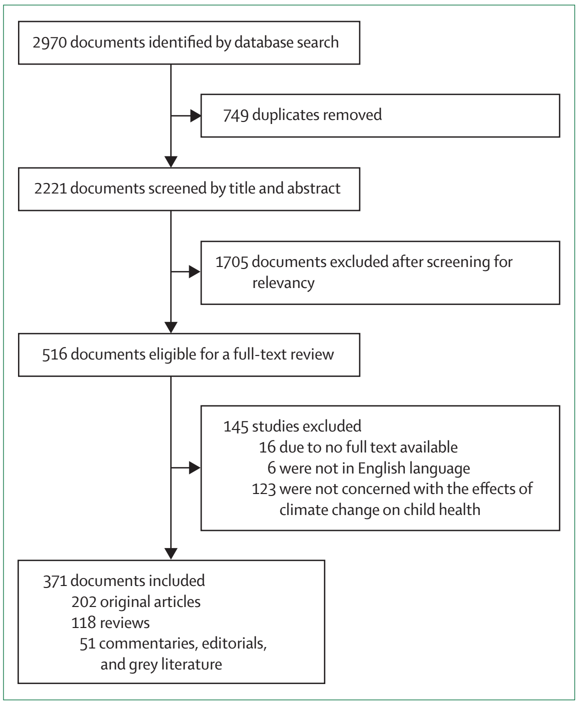

Figure 1: **Study selection process**
Documents refer to the material as a whole (original articles, reviews, commentaries, editorials, and grey literature).

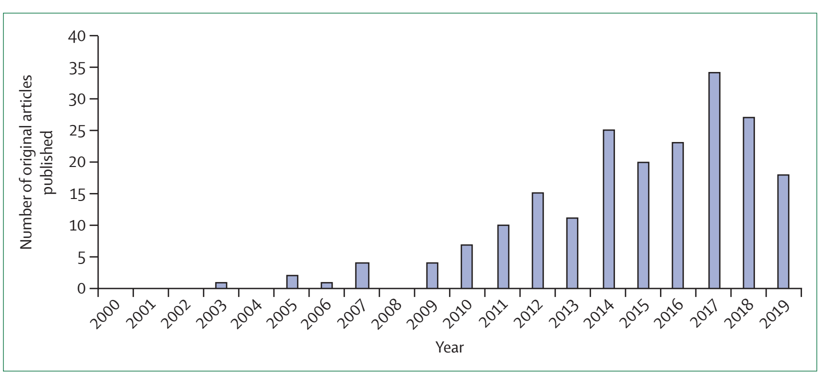

Figure 2: **Number of original articles published between 2000 and 2019**
In 2019, only published articles before June 11 were counted.

studies from Jan 1, 2000, to June 11, 2019, were considered. The detailed search strategy and PRISMA Extension for Scoping Reviews are available in the appendix (pp 2–3).

See Online for appendix

A screening of the retrieved literature was done by DH by reviewing the titles and abstracts in terms of relevance to the research question—that is, the inclusion criteria being that the original article, review, commentary, editorial, or grey literature (collectively referred to as documents henceforth) found were concerned with children (as defined by the Convention on the Rights of the Child[7] as people younger than 18 years) and a climate-related exposure that could be a risk factor for child health. In this Scoping Review we assumed the statements concerning the exposure were accurate with respect to whether they were weather, climate, climate variability, or climate change as defined by the Intergovernmental Panel on Climate Change.[1] The relevant documents were considered for full-text review by DH and CA. The documents included for full-text review were assessed for eligibility; ineligible documents did not have a full text available, were not in English, did not concern children, or did not include variables or analyses relevant to climate change as previously defined. To validate the process, MN and TA independently reviewed a random sample of 10% of the documents included for full-text review, and any discrepancies with regards to inclusion were discussed by DH, CA, MN, and TA to reach consensus.

Data abstraction

A first data abstraction chart based on published frameworks on health and climate change[10,16,17] was developed and tested by DH and CA. This chart included generic document information; contextual aspects of the original articles and reviews such as study setting, study groups, and information on climate change-related exposures and climate-sensitive health outcomes, including heatwaves, air pollution, food and nutrition, infectious diseases, and mental health; and social determinants of health, such as poverty and violence. After inputting data from the included documents, DH and CA applied open coding[18] to revise the categories of the chart and establish key themes across the included material. From this chart, the conceptual framework was created and revised by all authors. Due to the large number of studies included in the Scoping Review and their different approaches, a critical appraisal of the quality of each study was deemed to be beyond the scope of this study. The few original or review articles (n=14) that exhibited severe quality gaps in the form of unspecified methods determined by the full-text review were hence reviewed but not included in the analysis. As a consequence of the large material considered, only the most relevant are referenced throughout the result section below; a list of all included documents can be found in the appendix (p 5).

Role of the funding source

The funder of the study had no role in study design selection, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

The initial search yielded 2970 documents, of which 749 were duplicates, leaving 2221 documents that were screened for relevance (figure 1). Of these, 1705 were excluded, resulting in 516 documents being considered for a full-text review. From these, 145 were excluded due to their full text being unavailable, they were not in English, or they did not include either a child or climate change component. The total number of 371 documents were reviewed (202 original articles, 118 reviews, and 51 documents of other types such as commentaries, editorials, and grey literature). There has been a marked increase in the number of original articles per year on the topic, as shown in figure 2. In 2019, only published articles before June 11 were counted.

As described in the table, the largest proportion of single country studies were in high-income countries, with only 12·2% in low-income countries, primarily done in countries in Asia and Africa. Approximately half of the studies included urban and rural settings, and almost all used some kind of quantitative analysis. Only a third of the articles disaggregated the results by sex. The age group(s) used to define a child were heterogenous and in some instances not explicitly stated, but the majority of studies focused on children aged younger than 5 years.

	% (n)
Income status (single country original articles, n=172)	
Low income	12·2 (21)
Low-middle income	22·1 (38)
Upper-middle income	24·4 (42)
High income	41·3 (71)
Geographical area (single country original articles, n=172)	
North America	19·8 (34)
South America	5·2 (9)
Europe	4·7 (8)
Asia	36·0 (62)
Africa	22·7 (39)
Oceania	11·6 (20)
Study setting (all original articles, n=202)	
Urban	29·7 (60)
Rural	19·3 (39)
Both	51·0 (103)
Study method type (all original articles, n=202)	
Quantitative	92·6 (187)
Qualitative	4·0 (8)
Mixed method	3·5 (7)
Results disaggregated by sex (all original articles, n=202)	
Yes	32·2 (65)
No	67·8 (137)

Table: Characteristics of the original articles included

The effects of climate change on child health

A conceptual overview of how a changing climate could affect child health is presented in figure 3. The framework details how greenhouse gas emissions lead to a changed Earth system with higher temperatures, altered rainfall, a rise in sea level, acidification of oceans, and an increased frequency of rapid and delayed onset extreme weather events. Direct effects of climate change include temperature changes (heatwaves and more rapidly changing temperatures), changing precipitation patterns with increased risk of floods, droughts, and wildfires. More indirect effects include ecosystem disruption, changing vector patterns, air pollution, and aeroallergens. Child health risks due to these effects can be categorised as: a cause of direct harm to children and an increase in the risk of disease. Figure 3 also incorporates how these effects interact with human activity and the concepts of mitigation and adaptation.

Direct effects

The direct effects of climate change in the form of changing weather patterns—for instance, rapid and delayed onset extreme weather events such as storms, heatwaves, and flooding, are associated with childhood morbidity and mortality.[19] However, the underlying evidence of how climate change could directly affect adverse health outcomes is limited.[10,20]

Temperature changes

Children could be particularly at risk for negative health outcomes from rapid or delayed heatwaves.[21] Heatwaves increase overall mortality rates in a population.[22] Xu and colleagues[23] found inconclusive evidence of a higher risk of child mortality during heatwaves but the evidence was somewhat stronger for a heightened risk to infants than older age groups. Subsequent studies emphasised an increased overall mortality risk from heatwaves in children, particularly infants,[24,25] and multiple studies in low-income and middle-income settings[26–28] quantified the detrimental effect of heatwaves on child mortality rates, with some exceptions to this observed association.[29] Direct morbidity from heatwaves include heatstroke, electrolyte imbalance, kidney-associated diseases, and respiratory as well as infectious diseases,[23,30,31] whereas increases in mean temperature are associated with a higher prevalence of paediatric kidney stones and Kawasaki disease. Emergency department visits by children in cities increase during heatwaves,[32] especially among infants,[33] with the magnitude of risk differing between and within countries.[34] Asthma might be the most common cause for heatwave-associated respiratory disease.[35,36] Heatwaves might also result in an increase in unintentional injuries.[37] Combining socioeconomic and demographic factors with spatial modelling can forecast at-risk locations for increased heatwave-related mortality and morbidity.[38]

Increasing temperatures are not the only aspect that harm children. Studies describe greater mortality from cold temperatures among children in Madrid, Spain, and China,[39,40] whereas a rapid change of temperature and humidity levels can significantly affect respiratory and infectious diseases in children.[41,42]

Precipitation and floods

Rapid onset storms and heavy precipitation compound the risk of flooding and subsequent direct mortality and

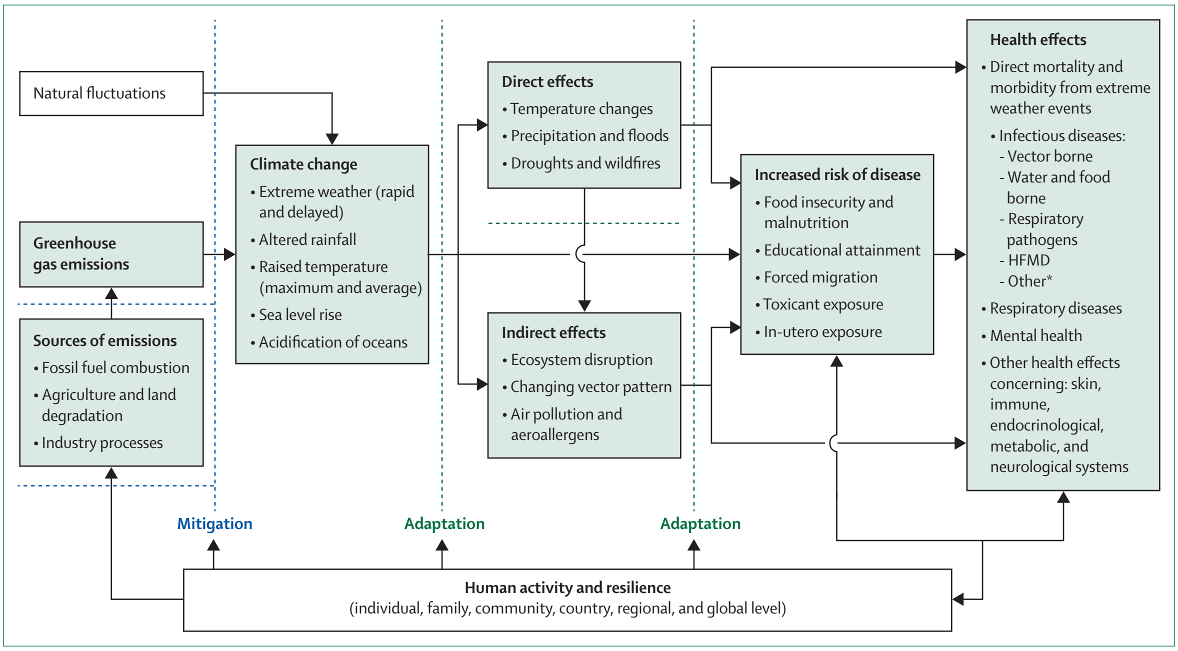

***Figure 3:* Climate change and child health: an expanded framework**
The dashed lines show where mitigation and adaptation can hinder the effects of climate change on child health and wellbeing. HFMD=Hand, foot, and mouth disease. *Other infectious diseases, from mumps to bacterial meningitis, varicella viruses, and parasitic diseases.

morbidity from drowning and unintentional injuries.[43,44] For child health, increases in precipitation are associated with overall higher mortality rates[45] and have long-term effects on child health due to lack of proper nutrition and the spread of communicable diseases. Flooding increases childhood mortality and morbidity[43,46] through amplified risk of infectious diseases, especially from water and food,[46,47] malaria, and respiratory infections, as well as its effect on the overall nutrition status of children,[48] and thus disproportionally affects the most vulnerable.

Droughts and wildfires

A lack of precipitation over time along with many other factors, such as evapotranspiration associated with increased temperatures, can lead to droughts. Droughts generally have a longer onset and duration than other weather and climate events.[49] Putting a strain on basic water needs for families in rural settings, droughts and drought-associated wildfires also contribute substantially to worsen respiratory health,[43] mental health,[50] undernutrition,[51] and infectious diseases among children.[52] Long-term changes in rainfall patterns, most notably lesser annual volume, affect child mortality rates in the Sahel region, Africa.[53] Despite potential adaptation strategies, droughts undermine local ecosystems, drive families into poverty, and can force migration.[49]

Indirect effects

Most indirect effects of climate change are multifaceted, acting over short and long timescales. These include ecosystem disruption, changing vector patterns, air pollution, and aeroallergens. Acting through a myriad of causes linked to climate change, mental health among children are also reviewed in this section.

Changing vector patterns and infectious diseases

The distribution of disease-carrying vectors are expected to be altered by climate change, whereas the transmission and survival of infectious pathogens will be influenced by changing weather patterns.[54,55] However, identifying specific infectious diseases that are sensitive to climate change remains difficult. Infectious diseases take a disproportionately high toll on children in general and socioeconomically vulnerable children in particular.[56]

The relationship between local or regional weather trends and the geographical range, seasonality, and prevalence of malaria is well understood. The long-term impact of climate change on the distribution of malaria vectors, the parasite itself, and child mortality and morbidity are under investigation.[57] In Uganda, short-term weather trend changes, plausibly due to climate change, leading to high temperatures and increased flooding, have led to more favourable conditions for malaria transmission, hampering vector control efforts.[58,59] Similar results have been found in Mali and Zambia. Generalising the net effect of climate change, intensified malaria transmission across sub-Saharan Africa could increase the malaria related under-5 mortality by 10–15% if no measures are taken to mitigate or adapt to climate change.[57] Using geospatial modelling based on the representative concentration pathways with the highest greenhouse gas emission (Representative Concentration

Pathway [RCP]), Semakula and colleagues[60] suggested that areas with high malaria prevalence will move towards eastern and southern rural Africa during this century.

Climate variability, particularly average temperature change, is associated with a change of geographical distribution of dengue,[61] with few quantifications of the associations specifically for children, although the burden of disease and deaths caused by the virus is highest among children in rural settings. One study estimated that almost half of the world's population could be at risk for dengue fever by the end of the century.[62]

Most prevalent in North America and Europe, the *Borrelia burgdorferi* bacteria that causes Lyme disease is transmitted by ticks, with children often being at most risk.[63] The lifecycles of the bacteria and tick are dependent on temperature and humidity, among other factors, and rising temperatures with climate change have expanded the geographical areas of transmission of Lyme disease into more northern parts of North America and Europe, and increase the risk of transmission in endemic areas.[54,64] A recent study projected a 20% increase in the incidence of the disease in the USA by mid-century compared with the current incidence rate under RCP 4·5.[64]

The multifactorial aetiology of diarrhoea has made it difficult to attribute cases to climate change;[62,65] a systematic review of the association between temperature and all causes of diarrhoea suggested however that climate change could be responsible for a substantial portion of diarrhoea cases.[66] Specifically, the prevalence of *Escherichia coli*, *Cryptosporidium*, rotaviruses, and parasites (eg, Giardia and toxoplasmosis gondii) increase with higher temperatures across many different climatic zones. Rural areas experiencing lower amounts of rainfall suffer from higher diarrhoea incidence rate among children due to the use of unsafe drinking sources and limited hygiene.[52,67] Conversely, higher precipitation levels in urban areas, both in low-income and high-income settings might increase diarrhoea incidence due to sub-optimal water and sanitation systems.[68,69] A warmer and dryer climate under RCP 8·5 could increase the intensity of rainfall in countries such as Botswana, South Africa, Senegal, Rwanda, and Ethiopia possibly leading to changes in patterns of childhood diarrhoea prevalence, underscoring the need for effective water and sanitation systems. Studies from India show that rainfall is associated with an increased prevalence of childhood diarrhoea; extrapolating past changes in climate could mean a 13% increase in childhood diarrhoea incidence rates in the northern states by 2040.[70] Increasing numbers of heavy rainfall and floods in Cambodia and China show that these events put children at risk for diarrhoea.[47,71] Evidence from other Asian countries emphasises that temperature is the most important weather variable associated with diarrhoea although this differed between geographical areas.[72,73]

Climate variability in the form of increased rainfall and humidity correlates with a higher risk of contracting bacterial and viral lower respiratory tract infections among children.[74] Studies from Australia and China show that rapid onset extreme weather events such as heatwaves, low temperatures, and heavy precipitation increase the vulnerability of children to a range of pathogens causing such infections.[75] Climate change will affect patterns of respiratory pathogens in both rural and urban settings.[74]

Hand, foot, and mouth disease (HFMD) is caused by enteroviruses that primarily infect children, and the prevalence of HFMD has increased in southeast Asia.[76] Examining the association between weather variables and HFMD suggests that the increased incidence of HFMD in China, Vietnam, and Japan is associated with higher average temperatures, precipitation, humidity, and air pollution in urban settings. Zhao and colleagues[77] have projected that the incidence of HFMD could increase by 3–5% by the end of the century in China, but the main impact would be a change in which urban areas would be prone to HFMD outbreaks. The trend and pattern appear to be true for other southeast Asian countries as well.[78] A changing climate could also affect the geographical range of other infectious diseases, from mumps to bacterial meningitis, varicella viruses, and parasitic diseases (eg, schistosomiasis).

Air pollution and aeroallergens

The effect of exposure of children to air pollution and aeroallergens, particularly on their respiratory systems, is detrimental. The air pollutants of particular concern with climate change are particulate matter and ozone. Aeroallergens will shift in seasonality and concentrations with climate change.

Particulate matter air pollution is a direct by-product of fossil fuel combustion and will worsen with climate change-related alterations in droughts, fires, and sand storms.[55,79] Exposure to particulate matter adversely affects lung function in children, with decreased peak expiratory flow and forced expiratory volume, particularly for children with asthma, leading to an increased number of emergency department visits, hospital admissions, and deaths in children.[80,81] Infant and child mortality reductions due to access to electricity in resource-limited and rural settings might actually be offset by air pollution from biomass and petroleum sources.[82,83] There could be an association between exposure to particulate pollution during pregnancy and children being small for gestational age, having low birthweight, and later presenting respiratory disorders,[84,85] although the results across individual studies are not consistent. Perera and colleagues[86] developed dose response curves between exposure to particulate matter during pregnancy and preterm birth, low birthweight, and incidence of asthma. There seems to be a reinforcing relationship between particulate matter and high temperatures and low humidity leading to a slightly higher risk of mortality and morbidity, but a more complex relationship regarding other climatic variables.

With increasing mean temperatures, constant emissions of precursor chemicals, such as nitrogen dioxide from fossil fuel combustion and biological processes, and no change in cloud cover, ozone concentrations are projected to increase especially in urban settings, but the extent will depend on local climatic variables.[87] Higher concentrations of ozone might exacerbate respiratory disorders such as asthma, atopic dermatitis, and allergic conjunctivitis. In South Korea, ozone pollution is projected to cause the majority of the burden of disease from climate change in children younger than 15 years during this century, assuming a balanced climate change model (A1B).[88] Other air pollutants from fossil burning sources such as transportation that can have a clear impact on child health both short term and long term are carbon monoxide, sulfur oxides, and nitrogen dioxide which similarly to ozone can worsen the respiratory function in children particularly for those suffering from asthma or other chronic respiratory diseases.[80,89]

Climate change and higher carbon dioxide concentrations, through increased mean temperature and greater precipitation, prolong and intensify the pollen season and affect the severity of allergic rhinitis, allergic conjunctivitis, atopic dermatitis, and asthma.[89,90] Understanding the burden of allergenic diseases due to climate change is difficult due to multifaceted causal pathways.[91] Neumann and colleagues[92] projected that emergency department visits from asthma caused by aeroallergens could increase by 14% in the USA over the course of this century under RCP 8.5 due to a longer pollen season. Additionally, warmer and more humid weather may increase the risk of fungal spore production, indoor mould growth, and insect and contact allergies.

Mental health

The implications of climate change on mental health of children has been poorly researched, although it has come under increased scrutiny during the last decade.[93,94] Burke and colleagues[93] suggested that climate change in the form of more frequent rapid and delayed onset extreme weather events and disruption of socioeconomic factors increases young people's susceptibility to mental health illness in the form of depression, post-traumatic stress disorder, and anxiety, and that climate change might lead to graver mental health illnesses, particularly among already disadvantaged children. Empirical qualitative studies on the effect of drought[50,95] and higher temperatures[96] on adolescent mental health in Australia and the USA show an overall worse mental health with higher levels of emotional and physiological distress. Studies from Sweden,[97,98] Canada,[99] and Australia[100] showcase how adolescents coped with the disruptions by focusing on the problem or building meaning around combating climate change. It has also been suggested that the effects of climate change might have long-term behavioural effects.

Increasing the risk of disease

Through direct and indirect mechanisms and over long and short timescales, climate change can affect deter minants of general child health and wellbeing. The key determinants found in this Scoping Review are detailed in this section.

Food insecurity and malnutrition

Malnutrition is one of the leading factors contributing to child mortality and morbidity globally.[54,56] The empirical evidence on how climate change will impact child health through the effect on nutrition is under development but mainly focused on rural areas.[101] The drivers of and interactions between undernutrition and overnutrition and climate change are complex.[102]

The majority of studies indicate that potential gains in crop yields from higher average temperatures and carbon dioxide concentrations would be offset by negative effects in the form of heatwaves, lower water availability, changes in the dynamics of crop diseases, and lower nutritional value of crops (for instance lower concentration of iron in foods).[54,103,104] Extreme weather events such as flooding have long-term effects on the nutrition status of children, with the most disadvantaged children being at greatest risk.[48,105,106] Studies in west Africa, Ethiopia, Kenya, and around the Lake Victoria Basin, where the crop yield and other agricultural variables were compared with undernutrition in children, showed that decreases in such variables due to droughts lead to a higher probability of child undernutrition. A number of studies modelled changes in temperature and precipitation due to climate change based on RCP 8·5 over the coming decades, and projected that sub-Saharan Africa could face increased rates of stunting of up to 20% depending on rate of socioeconomic development[101,107,108] but that this would vary substantially within countries. Crop diversification has been identified as a possible adaptation measure in combating child undernutrition.[109] The rapid economic growth of Asian countries has led to lasting undernutrition in rural areas and overnutrition in cities.[110] Lastly, studies have emphasised that there are macro and micro economic, environmental, technological, cultural, and societal determinants that influence the drivers of child undernutrition due to climate change,[111] and that the economic impact might be negligible.[112]

Patterns of nutritional intake by children and the built environment interact to facilitate unhealthy diets and decreased levels of activity, leading to increased risk of overnutrition.[113] Similar to undernutrition, the risk factors associated with overnutrition have been found to be most prevalent among socioeconomically vulnerable children in urban settings.[113] Indeed, overnutrition, undernutrition, and climate change seem to have a common set of causes requiring a systematic approach to finding and implementing solutions.[102]

Socioeconomic distress, education, migration, and toxicant exposure

Not many studies directly examine the more distant determinants of child health and their relation to climate change. It is clear, however, that the health effects of climate change will magnify already existing child health inequities.

Climate change could force families into poverty through loss of livelihood, additional costs from property damage, and health costs.[54] Particularly vulnerable are populations already living in poverty or near poverty in rural geographical areas that will probably be affected most from climate change such as low-elevation coastal zones due to sea level rise, less-favoured agriculture areas, or the Arctic region. The wealth of individuals and families will be important factors when adapting to climate change.[114] The impact of climate change-related extreme weather events on child poverty rates seems to be indifferent to the quality of governance structures.[115] Climate change affects the broader societal context, with studies describing how disruptions such as storms in Bangladesh have increased the risk of early child marriage as a way of coping with economic loss[116] and that gender violence weakens the resilience of communities.[117] Another vulnerable subgroup of children are those who lack a social security net.[118,119] The many and different social, economic, and environmental determinants that are affected by climate change often amplify the health impact on children particularly in low-income settings.[120] At the same time, children are themselves agents of change and an integral part of the resilience of families and communities.

Climate variability, including higher temperatures during prenatal and early childhood years, can lead to significantly less educational attainment, but the relationship between rainfall and level of education differs across regions and rural and urban settings.[121] High ambient air temperature during schooling leads to negative effects on the wellbeing of children,[122] whereas females experiencing droughts during childhood have lower educational attainment.[51] In turn, low education has often been cited as one reason for low socioeconomic status that leads to disproportionally higher risk from the effects of climate change. The potential of schools in addressing health impacts from climate change is largely unknown.

Few articles investigated migration as a result of climate change and its impact on child health, but it is expected that losses of sustainable water sources due to sea level rise and flooding could be one of the key drivers of migration.[123] Examining the migration pattern in response to natural disasters in Bangladesh, Penning-Rowsell and colleagues[124] concluded that migration occurred either for fear of safety or for economic reasons, but that permanent migration was only seen as a last resort.

Due to the increased frequency of extreme weather events and overall changes in temperature and precipitation from climate change, it is probable that children's exposure to toxicants such as organic pollutants, pesticides, metals, and other toxicants could increase.[55] Exposures to aforementioned toxicants can not only lead to acute poisonings, but also to long-term adverse health effects such as endocrinological or neurological dysfunctions.[120]

In-utero exposure

The effects of climate change on pregnant mothers are beginning to be understood, with studies focusing on the intersection between maternal and child health with regards to climate change.[125]

Extreme temperature changes during pregnancy have been associated with an increased risk of preterm birth, but the association varies across studies,[126,127] and does not appear to be significant in some high-income contexts.[128] Water scarcity due to climate variability has also been identified as increasing the risk of preterm birth.[129] Extreme temperatures, low amounts of precipitation, and high levels of air pollution have led to lower birthweight and affected length at birth, which has implications for the health of the neonate and development of the child.[84,128,129] The magnitude and association between climatic variables and birth status vary, but climate change could lead to lower average birthweights in sub-Saharan Africa over the coming decades.[130] Some studies suggest that higher average temperatures increased the prevalence of birth defects.[131] There are also indications for a connection between extreme temperatures and miscarriages and stillbirths,[132,133] whereas higher water salinity at the end of the pregnancy from rises in sea level or flooding points to an increase in the risk of neonatal death.[134] Rapidly changing and extreme temperatures during pregnancy was linked to childhood pneumonia,[135,136] air pollution, and childhood atopic eczema,[137] whereas mental health illness during pregnancy following rapid onset extreme weather events impacted infant behaviour[138] and child height. There are also some indications that increased in-utero exposure to particular matter and other air pollutants could have physical, cognitive, and behavioural effects on the child later on in life.[86] Early evidence showed that high temperature exposure in utero led to a small reduction in adult wages in the USA;[139] however, the exact implications for other outcomes remain unclear.

Discussion

Climate change and child health is a new field of inquiry, with the first review dedicated to the subject published in 2003[140] and subsequently advanced by the American Academy of Paediatrics in 2007,[141] as well as Ebi and Paulson in 2007 and 2010.[63,142] Our review assesses the current evidence on how climate change can affect child health, synthesising a vast body of literature, and presents an expanded framework that can be used for understanding and positioning climate change and child health within the sustainable development discourse. Of the 202 original articles included, almost all were published during the last 5 years. Albeit having a relatively equal geographical distribution, most of the studies were confined to upper-middle-income or high-income countries, consistent with previous evidence summaries.[10,16,54,55,63,142–144]

The prevailing inequalities, between and within countries, largely determine how climate change impacts children. Disadvantaged children suffer from a disproportionately high and truly unjust health burden from climate change.[145] Further, the impact of climate change seems to follow an urban and rural divide, although not consistently. This pattern is probably due to the differences in the environment,[146] access to health care, and socioeconomic factors.[147] The difficulty of deciphering weather variability due to climate change and the attributable health impact was acknowledged by almost all studies. Other factors might cause a certain outcome, and there remains a great level of uncertainty when it comes to measures of climate change health impacts on children.

Previously identified research gaps within the area of climate change and child health have not been addressed to satisfaction. First, the large number of articles found masks a striking lack of focus on climate change and child health; many studies only include children as a subpopulation of analysis. Second, although there exists research from low-income settings, most studies were still done in high-income and upper-middle-income countries and focused on particular countries. Third, there was little evidence of the beneficial or harmful effect of social, political, and commercial determinants on climate change impacts on the physical and mental health of children and different scenario projections taking these and different climate change scenarios into account. Fourth, few articles disaggregated the analysis by sex and age group, limiting the generalisability and usability of results. Fifth, the health outcomes that are the basis of the assessment of climate change impact on children vary to such a large degree that it is almost impossible to compare results across studies. Last, there is a clear lack of qualitative research and longitudinal studies, restricting a fuller understanding of how climate change affects child health and wellbeing.

Several potential areas for future investigation were found. The use of temporo-spatial modelling, providing detailed estimates of child mortality,[148] could untangle complex relationships between climate change, weather patterns, and health impacts. An unexplored area comprises the co-benefits of climate change mitigation and reduced ill health for children, concretely exemplified by the linkage between fossil fuel use both at a household and societal level and subsequent air pollution.[83] There is also a great need for studying adaptation, with vital societal functions such as access to safe and quality water and sanitation services being key for developing resilience against climate driven infectious disease outbreaks. Situating climate change effects within the framework of the UN Sustainable Development Goals further enables the holistic exploration of interlinkages between climate change, child health, and other societal sectors.[149] The research gaps found should not be an excuse for inaction; our findings show that there is clear impetus for policy makers to strengthen mitigation and adaptation efforts.

A clear strength of this Scoping Review is the bringing together of a wide variety of studies using a systematised search strategy providing a broad overview of the area. When trying to synthesise such a complex topic there are certain limitations and potential for biases. First, we restricted the search in terms of time, language, and few search terms, which inherently have led to excluding some studies that did not include the search terms as MeSH terms or free text. As with all literature searches, there is a risk of publication bias, which, due to the large number of studies indicating causal relationships found, is deemed likely. Second, we did not publish the protocol of the study due to time limitations and only one investigator (DH) did the screening process and, although validated procedures were in place, the inclusion process could be limited by selection bias. However, the data extraction and quality assessment were done by two investigators (DH and CA) in cooperation to ensure consistency and we explicitly state which documents we refer to in this review and make all included documents available in the appendix (p 5). Third, we do not provide any appraisal of the level of uncertainty for each association described, if the authors accurately described their association as weather, climate variability, or climate change or a definitive conclusion on the potential heightened risk or similar measurement; hence, the actual impact from climate change and the described aspects cannot be asserted within a particular population. In summary, the strengths and limitations of this review mirror the challenges and opportunities within the field of climate change and child health.

The effects of climate change on child health travel through many different pathways, vary substantially across geographical locations, and are heavily influenced by broader socioeconomic contexts. By using a diverse range of novel research methods, studying overlooked populations and geographical regions, and investigating the benefits of mitigation and adaptation to child health, crucial knowledge gaps can be filled. Rejuvenating innovative research efforts across disciplines is crucial to fill these gaps, where situating climate change and child health within the UN Sustainable Development Goals will be key. Still, present and future generations of children, particularly the already vulnerable, bear and will continue to bear an unacceptably high disease burden from climate change.

Contributors

TA and MN generated the study idea. DH, CA, TA, and MN designed the analysis and methods. DH and CA reviewed the literature. DH and CA

did the analysis, and DH wrote the first draft of the manuscript, to which all authors contributed. KLE and PF participated in the analysis and provided critical scientific input on the manuscript.

Declaration of interests

DH, CA, MN, and TA report grants from Formas (FR-2018/0010) during the conduct of the study. All other authors declare no competing interests.

Data sharing

All data are available in the paper and appendix.

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