Systematic review of climate-change interventions to improve child health

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Abstract

Background: Climate change is the "… single biggest health threat facing humanity" according to the World Health Organization, and children under five years old bear an estimated 88% of the additional disease burden. Changing temperature and rainfall patterns have increased heat-related illnesses, vector-borne diseases and adverse birth outcomes, while exacerbating food insecurity leading to malnutrition. Air pollution has adverse impacts on birth outcomes and respiratory health in children. Many interventions have been introduced to reduce the harm of climate change on child-health outcomes, but few have been assessed scientifically. We did a systematic review to synthesise the available evidence on tested interventions to improve child health in response to the impacts of climate change.

Methods: We searched *PubMed, Medline, Embase* and *Google Scholar* for relevant literature published up to 14 March 2024. We included all study types published in English that evaluated a

child health outcome in response to a climate change intervention. We identified the target populations, outcome measures and descriptions of the interventions. We applied the *Grading of Recommendations, Assessment, Development and Evaluation* (GRADE) approach to assess the quality of evidence of each study, excluding reviews.

Results: Of 4381 records identified, 58 met the eligibility criteria. The quality of evidence was predominantly *moderate* to *very low*. Interventions addressed health outcomes relating to: **environmental factors**: (*i*) heat (*n* = 16), (*ii*) water, sanitation, and hygiene (*n* = 3), (*iii*) food insecurity and undernutrition (*n* = 4), (*iv*) disasters and extreme weather (*n* = 6); and **specific health issues**: (*v*) respiratory illness (*n* = 5), (*vi*) mental health (*n* = 2), and (*vii*) vector-borne diseases (*n* = 6). The co-benefits of **mitigation** on child health outcomes was studied in 17 papers. Heat-related morbidity was reduced via maternity ward relocation and preseason high school sports guidelines. Low birth weight was reduced via cash transfers to pregnant women, rainwater collection, and green space. Childhood underweight was improved via household-level livelihood diversification. Respiratory outcomes were improved via retrofitting buildings with insulation and administering pneumococcal conjugate vaccines. Malaria incidence and mortality was reduced via insecticide-treated nets, indoor residual spraying, and artemisinin combination therapy. Classroom-based sessions related to climate change increased mental wellbeing, as well as knowledge of climate risks and adaptation behaviours. Overall, reports of mitigation policies consistently found co-benefits in improving infant mortality, respiratory outcomes, adverse birth outcomes, and life years lost.

Findings: Current global evidence of which interventions are successful is scarce, heterogenous, and of inconsistent quality. A robust scientific demonstration of effectiveness is needed for child-health interventions within climate change policies to ensure they are effective.

Introduction

Climate change has been declared the "… single biggest health threat facing humanity" by the World Health Organization.[1] Increasing global greenhouse-gas emissions due to unsustainable energy consumption and land use have accelerated the rate of global surface temperature increase to its highest over at least the last 2000 years.[2] The United Nations Intergovernmental Panel on Climate Change has warned that exceeding a 1.5 °C increase in average global temperatures will have devastating impacts on human health, livelihoods, and infrastructure.[2] Alarmingly, this limit has already been exceeded as average temperatures reached 1.52 °C from January 2023 to February 2024.[3] Rising temperatures also contribute to increasing frequencies of extreme weather events

(including cyclones, droughts, and floods), which exacerbate adverse health impacts.[2] Increasing ambient air pollution is further harming health, with negative effects on respiratory and cardiovascular health[4] and infant mortality.[5]

The adverse health effects of climate change are not distributed equally, either by age or location. Children under five years old bear 88% of the additional disease burden caused by a changing climate.[6] As the global human population continues to grow, an increasing number of children will experience worsening effects of a deteriorating climate. Climate change affects health from conception, with impacts ranging from preterm births, increased incidence of communicable and non-communicable diseases, malnutrition, and mortality.[2] Current trends threaten progress towards several United Nations Sustainable Development Goals, including Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-Being), Goal 6 (Clean Water and Sanitation), and Goal 13 (Climate Action).[7] People living in low- and middle-income countries who have contributed the least to climate change are the most severely affected, particularly children who have no personal autonomy.[2]

The relationship between climate change and adverse effects on child health is well-established,[8] but despite recognition of the growing threat, there is a paucity of research available on the effectiveness of interventions aiming to reduce the adverse effects of climate change on child health.[9] Such evidence is needed to guide policymakers on practical solutions to protect children amidst the rapidly accelerating environmental crisis. Our aim in this review is therefore to examine the available literature on intervention and relevant policies.

Methods

We did a *Preferred Reporting Items for Systematic reviews and Meta-Analyses* (PRISMA) systematic review[10] to address the main question: what interventions lead to improvements in child health to adapt to the effects of climate change? We first constructed a search string incorporating terms relating to climate change, interventions, children, and various health outcomes (Table 1). Our approach to the literature search (Figure 1) was to query several databases, including *PubMed*, *Medline*, and *Embase* on 14 March 2024. We also did a Google Scholar search to identify grey literature; we retrieved records by relevant title until all results on the page were no longer relevant for three consecutive pages. We screened all records according to inclusion and exclusion criteria in Table 2. Given the scarcity of relevant literature, we designed the search string to encompass a

broad range of health outcomes, and excluded nothing based on study type or date published. We also included articles assessing outcomes associated with increased awareness of health risks and/or changes in health behaviours, despite being inconclusive regarding whether these outcomes improved child health. The lead author (JU) applied the *Grading of Recommendations, Assessment, Development and Evaluation* (GRADE) approach to rate the quality of evidence of each article.[11] We designated quality as *high*, *moderate*, *low*, or *very low*. We excluded all reviews from the quality assessment, but included their findings when they reported generalised results. Due to the heterogeneity and scarcity of interventions and quantitative health outcomes, a meta-analysis was not possible.

Table 1. Terms used in the search string, divided into four categories. Each category was connected by the Boolean term "AND".

Climate change	Interventions	Children	Health
"climate change" OR "global warming" OR "greenhouse effect" OR "extreme heat" OR "hot weather" OR "high temperature" OR "ambient temperature" OR "heatwave" OR "weather"	"policy" OR "climate polic*" OR "policies" OR "intervention*" OR "climate adaptation" OR "adaptation"	"child" OR "children's" OR "adolescent" OR "fetal" OR "foetal" OR "infant" OR paediatric* OR pediatric* OR neonat* OR prenatal OR perinatal OR postnatal OR pregnan* OR "maternal"	"health" OR "preterm birth" OR "type 2 diabetes" OR "respiratory infection" OR "respiratory" OR "emergency department" OR "heat stroke" OR "mental health" OR "asthma" OR "mortality" OR "morbidity" OR "nutrition" OR "undernutrition" OR "malnutrition" OR "stunting" OR "ecoanxiety" OR "eco-anxiety" OR "climate anxiety" OR "mosquito" OR "mosquito-borne" OR "vector-borne" OR "dengue" OR "malaria" OR "disaster risk"

Table 2. Inclusion and exclusion criteria for studies.

Inclusion	**Exclusion**
English language	non-English language
relevant to climate change	not relevant to climate change
evaluation of a health intervention or policy describing clear outcome/s relating to health	not an evaluation of a health intervention or policy; no health outcome described
target population < 18 years, or pregnant women	target population ≥ 18 years and not pregnant women

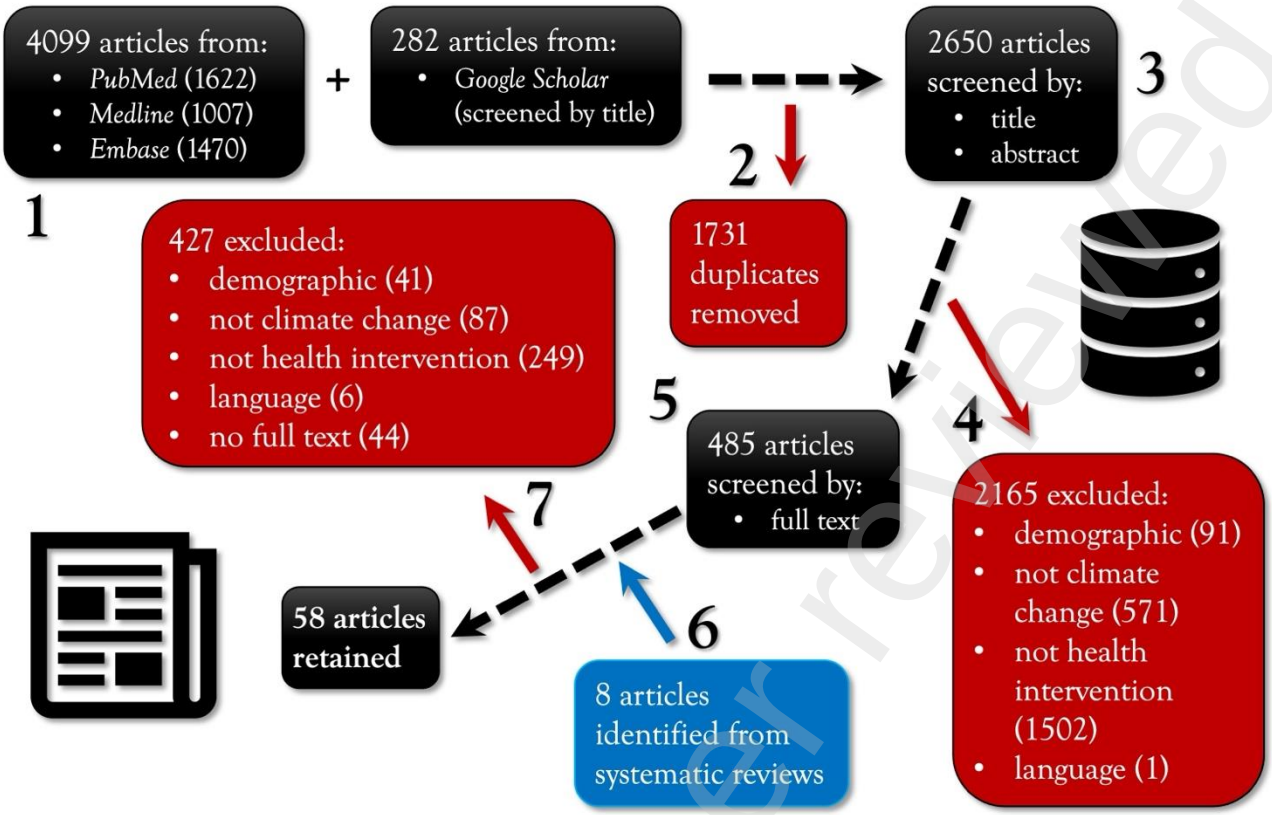

Figure 1. Approach to screening and reviewing relevant articles identified by literature search.

We retrieved 4099 articles from *PubMed*, *Medline* and *Embase*, and 282 articles from *Google Scholar*. We removed 1731 duplicates before screening. The lead author (JU) screened the identified studies according to the process outlined in Figure 1. We first screened articles by title and abstract, excluding 2165 articles. We then screened the remaining 485 by full text, as well as an additional 8 articles retrieved from relevant systematic reviews. We found 58 that met the inclusion criteria, evaluating the effects of an intervention on child-health outcomes in response to climate change. We tabled relevant information from each article, including the climate risk factor addressed, intervention, health outcome, health metric, target population, and study type.

Results

We included 58 papers in our systematic review, and based on which aspect each of these addressed, categorised interventions into seven themes, four of which were environmental (i to iv) and three specific health issues (v to vii): (*i*) heat (n = 16), (*ii*) water, sanitation, and hygiene (n = 3), (*iii*) food insecurity and undernutrition (n = 4), (*iv*) disasters and extreme weather (n = 6), (*v*) respiratory illness (n = 5), (*vi*) mental health (n = 2), and (*vii*) vector-borne diseases (n = 6). We categorised one paper under both heat and respiratory illnesses. Seventeen papers evaluated the co-

benefits on children's health of climate-change mitigation (i.e., reductions in greenhouse-gas emissions). We provide a list of all included literature in Appendix A and GRADE scores and corresponding explanations in Appendix B.

The rate of studies published has increased (Figure 2), with 65% published within the last five years. Studies on mitigation co-benefits began to be published the earliest and mental health the latest compared to other themes.

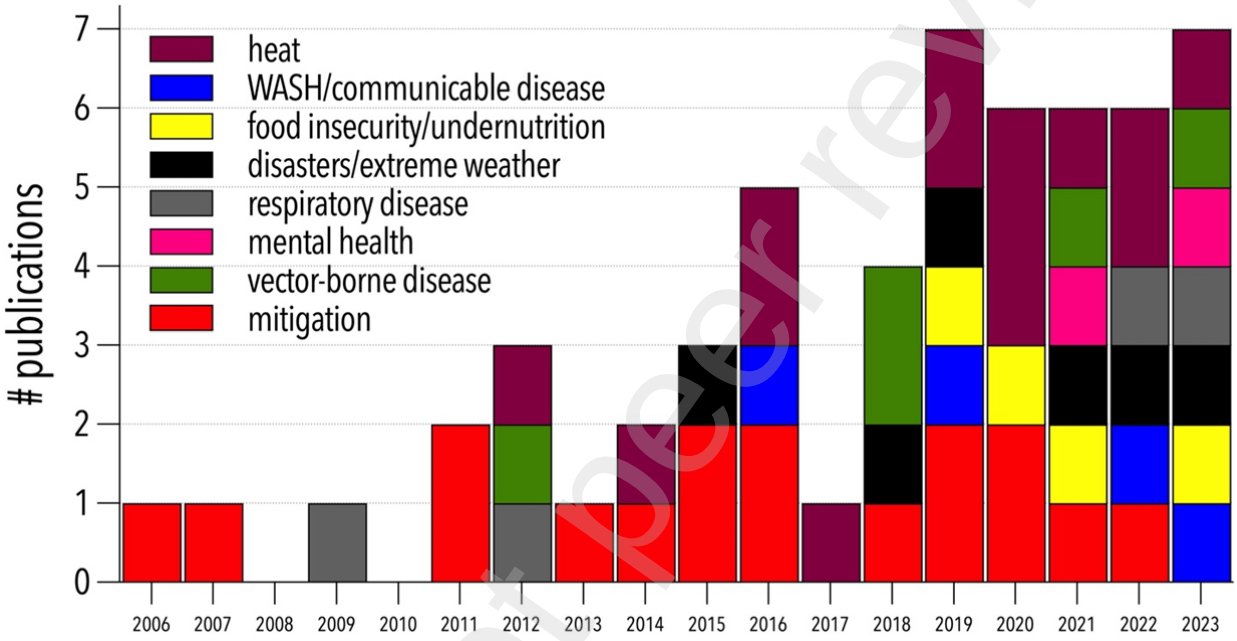

Figure 2. Number of studies examining climate-change interventions for children published between 2006 and 2023. WASH stands for water, sanitation and hygiene.

Using GRADE criteria, only five studies had *high*-quality evidence; *moderate*-quality studies were the most common (n = 20), followed by *very low* (n = 13), then *low* (n = 10). Studies on mitigation co-benefits were the most common and had the highest-quality evidence overall, with most incorporating quasi-experimental statistical designs. There was a gap in robust evidence to address mental health; the two relevant studies were qualitative and did not assess specific mental health issues, and had *very low* quality evidence. For all other intervention categories, most studies were observational, resulting in lower-quality evidence. Of the four studies that incorporated a randomised, controlled-trial design, all had their evidence quality downgraded due to their use of surrogate outcomes and/or convenience sampling. Forty-nine studies were retrospective and nine were prospective.

Mapping the geographical distribution of studies (Figure 3) revealed that studies examining pollution were mainly in high-income countries, whereas those focused more on precipitation-related climate events (e.g., droughts and floods) were based exclusively in low- and middle-income countries (most in sub-Saharan Africa).

The health metrics examined in relation to interventions (Table 3) showed that child mortality was measured uniformly across the globe. Studies measuring perinatal and respiratory outcomes were done mainly in high-income countries. Studies measuring nutritional outcomes and vector-borne disease morbidity were primarily in sub-Saharan Africa.

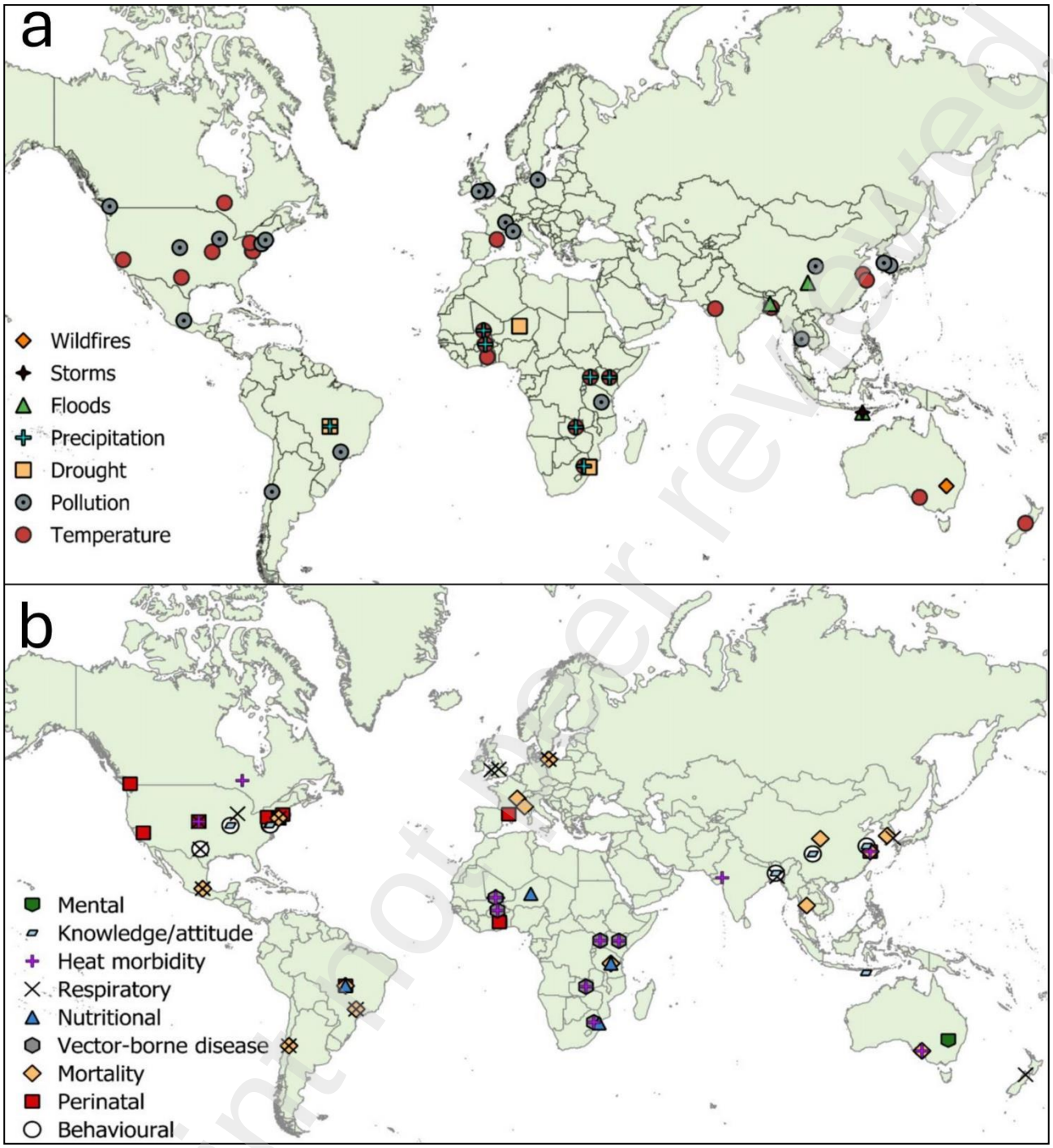

Figure 3. (a) Studies mapped by climate variable and (b) child-health outcome. Global reviews excluded.

Table 3. Health metrics examined in relation to interventions.

Health outcome	Metric
mortality	all-cause mortality; cardiovascular mortality; respiratory mortality; malaria case fatality rates
heat morbidity	prevalence; neonatal intensive care unit admissions; incidence; ambulance callouts; hospital admissions; emergency department presentations
perinatal	preterm birth; low birth weight; birth weight; small-for-gestational-age; large-for-gestational-age; gestational age; low 5-min Apgar score; foetal growth rate; weeks of gestation; anaemia during pregnancy; iron folate supplementation coverage for women
nutritional	weight-for-height (wasting); height-for-age (stunting); weight-for-age (underweight); body mass index; children's dietary diversity score

respiratory	asthma prevalence; respiratory hospitalisations; missed days of school; emergency department presentations; asthma exacerbations not requiring medical care; lower respiratory infection; lower respiratory symptoms; acute bronchitis; respiratory medication use
vector-borne disease morbidity	parasitaemia prevalence; severe anaemia; malaria incidence
mental	well-being
knowledge and attitude	post-intervention knowledge test scores; perceived and actual knowledge of health risks; perceived risk of maternal and child health harms; self-efficacy in reducing health risks; intention to engage in health risk reducing behaviour
behavioural	interaction with green features; physical activity; shade behaviour during recess time; health behaviours (e.g., washing hands)

Heat

Heat interventions are needed as rising ambient temperatures due to climate change have been associated with adverse pregnancy outcomes, including preterm birth[12] and low birth weight.[13] Heat might interact with air pollution to exacerbate preterm birth.[12] Thermal discomfort can discourage children from engaging in physical activity.[14]

Half of the 16 studies explored green space as a heat-reduction intervention, but studies reporting pregnancy outcomes relative to green-space use were inconsistent. Two studies found positive effects of green-space exposure on birthweight[15] and decreases in preterm birth,[12] while others found no association.[16,17] The discrepancies could be due to socioeconomic variation that explains health differences rather than exposure to greenness *per se*[18]; for example, a study in Ghana found that cash transfers to pregnant women mitigated low birth weight due to high ambient temperatures throughout pregnancy.[13] The remaining studies evaluated children's interaction with green features for thermal comfort and physical activity. Children use green features as refuges from heat[14,19] and were associated with greater time spent in moderate to vigorous physical activity.[14]

Four studies evaluated existing heat-wave warning systems such as heat alerts through media, followed by a range of responses such as opening shade shelters[20] or cooling stations,[21] and providing targeted outreach to priority groups.[21,22] A system implemented in Adelaide, South Australia reduced heat-related ambulance call-outs, admissions and Emergency Department presentations, but not mortality.[22] A similar system in South Korea was associated with reductions in all-cause, cardiovascular and respiratory mortality.[20] However, the warning system used in Ontario, Canada found no changes.[21] In Shanghai, China, 50% of heat-related illnesses occurred on days with a daily maximum temperature below the warning threshold.[23] One study in India found that moving the maternity ward in a hospital to the cooler ground floor after a heat wave was associated with a decrease in neonate admissions to the neonatal intensive-care unit for heat-related illnesses.[24]

Educational interventions included primary school-based activities[25] and brochures for pregnant women.[26] Both interventions were followed by increases in knowledge about health-adaptation behaviours to extreme heat. However, a major limitation of these studies is the lack of assessment of whether this knowledge translated into behavioural change that resulted in improved health. The U.S. National Athletic Trainers' Association Inter-Association Task Force has designed school-based interventions for high school athletes participating in preseason sport, including gradual 'acclimatisation' for two weeks prior to the sport season, and a three-hour limit for practice sessions. These guidelines were associated with reduced reports of exertional heat illness in high school athletes.[27]

Water, sanitation, and hygiene

Changing rainfall patterns, freshwater availability, and heat events due to climate change create challenges for adequate delivery of water, sanitation, and hygiene services, exacerbating the burden of diarrhoeal disease.[28] In low- and middle-income countries, vulnerable groups (including children) are disproportionately at risk of food- and water-borne disease due to increasing frequency of flooding.[29]

Interventions to alleviate water stress due to less predictable freshwater availability have displayed positive effects on child-health, such as in Brazil where rainwater collection via cisterns was associated with small reductions in the incidence of low birth weight and preterm birth.[30]

National poverty-reduction programs (such as conditional cash transfers and community-driven development) might be more cost-effective than interventions for individual behavioural change to control food- and water-borne disease at scale.[28] School-level interventions, such as the establishment of hand-washing facilities in front of latrines, were also identified as important for the additional food- and water-borne disease burden induced by climate change.[29]

Food insecurity and undernutrition

Climate change-induced droughts and floods leading to chronic food insecurity in vulnerable regions are associated with poor maternal and neonatal nutritional outcomes.[31] All the studies we identified in this category focused exclusively on low- and middle-income countries, and three of the four interventions considered aimed to reduce poverty. A 2019 study of farmers in Eswatini, Africa after severe drought reported that livelihood diversification was positively correlated with improvements in child anthropometry.[32] Conversely, the other two studies did not report any

positive effects. Brazil's Zero Hunger program providing free school meals and financial support for small-scale family farmers and families in poverty did not lead to reduced child malnutrition and infant mortality.[33] An agroecology program in Tanzania improved children's dietary diversity, but this did not translate into improved child anthropometric outcomes.[34] Impacts of existing food-security policies and programs in Niger were acute, suboptimal, and associated with inconsistent maternal and neonatal nutrition indicators and mortality rates.[31]

Disasters and extreme weather

Changing climate patterns are causing more frequent and intense extreme weather events, including wildfires,[35] droughts, floods, and storms[2]; exposure to which can lead to adverse mental health outcomes for young children.[36] Despite their disproportionate impacts on children, many existing disaster risk-reduction programs and strategies do not actively involve the participation of children.[37] Some papers reported educational interventions in schools. In China, classroom education, posters, and professional guidance increased children's perception of flood risk.[38] Likewise, preschool education in Indonesia increased children's knowledge of warning signs, who to contact for help, and safe spaces to seek during extreme weather or natural disasters.[39] However, whether increased risk perception and knowledge improve child health is still unclear. Mental well-being was the only outcome considered in the remaining educational studies. A systematic review explored the evidence on post-disaster support of mental health through teaching strategies on resilience-building — these might be effective for improving student mental health and well-being, at least in the short term.[40] Another review found that studies of disaster-risk education generally showed evidence of greater awareness, knowledge, confidence, and positive mental states in children.[37]

The available literature on climate change related interventions for pregnant women was entirely qualitative. Deploying midwives to rural primary health centres following the 2022 flooding in Bangladesh was successful in building rapport with patients and helping them to navigate health services[41]; however, direct improvements in maternal health outcomes were not measured. A review on wildfire smoke exposure during pregnancy identified some evidence that high-efficiency particulate air filter use was associated with greater birth weight, and that well-fitting N95 respirators are accessible and benign tools to reduce exposure to air pollution. The review also found that behavioural modifications (staying indoors and avoiding strenuous activity during wildfire events) improved health outcomes in the population, but acknowledged that such interventions have not been tested in pregnant women explicitly.[35]

Respiratory illness

Extreme temperatures and air pollution exposure have been correlated with increased prevalence of respiratory illnesses, including asthma[42] and childhood pneumonia.[43] In response, retrofitting school buildings and houses with insulation and its relationship with respiratory outcomes has been evaluated. In the United Kingdom, improving the energy efficiency of schools to decrease NO_2 exposure reduced asthma incidence when combined with increased ventilation. Without ventilation, the opposite effect was observed, potentially due to overheating.[44] Retrofitting houses with insulation reduced the number of missed school days and rates of respiratory hospitalisation.[45] Another study explored the impact of green space on childhood asthma and found no relationship between vegetation/tree cover and asthma incidence.[46] Only one study has focused on education and respiratory illness — a controlled trial in the U.S. in 2020 provided brochures on the risks of heat and air pollution to pregnant women. Narrative was more effective than didactic information in improving women's perceived risk, self-efficacy, and behavioural intentions (intentions to stay indoors during heatwaves or periods of poor air quality, and to ask doctors or nurses about strategies for protection).[26] Like many other studies on educational interventions, whether these results had any impact on health outcomes is unclear. One study found that pneumococcal conjugate vaccines might help decrease cold-related, but not heat-related, childhood pneumonia hospitalisations.[43]

Mental health

Heatwaves, extreme weather events and the long-term impacts of climate change (i.e. economic loss, displacement, threats to health and well-being, violence and civil conflict, degraded environments) have been associated with mental health challenges.[47] Depression, anxiety, and post-traumatic stress are the most common conditions, with children being especially vulnerable.[47] Climate-related disasters such as bushfires and floods are traumatic events that can promote young people separating from family and community, cause adverse mental health outcomes for both parents and children, and elicit feelings of grief and loss.[36]

Only two intervention studies met our inclusion criteria: (*i*) A 2023 study in New South Wales, Australia evaluated the impact of post-bushfire counselling on young children's mental health without controls.[36] Sessions focused on strategies for resilience-building and communicating emotions, leading to short-term improvements in social communication, emotional development, and functioning at school, home, and social situations. However, the study was qualitative and did not specify the targeted age. (*ii*) A systematic review of green schoolyards found that almost all

studies reported beneficial effects on children's socioemotional health. However, a few studies reported no impacts, or negative impacts on social behaviour in older children.[48]

Vector-borne disease

Increasing rainfall due to climate change has been associated with increased malaria incidence.[49] Additionally, increased land surface temperatures and decreased vegetation have been associated with reductions in the decline of malaria incidence.[50] Incidence of dengue and other vector-borne diseases are also rising as changing climate conditions create more favourable environments for disease vectors.[51] Several studies have examined retrospective implementations of insecticide-treated nets, indoor residual spraying, and/or artemisinin combination therapy in low- and middle-income countries. Reductions in malaria incidence and mortality were associated with the use of insecticide-treated nets[49,50,52-54] and indoor residual spraying.[53,55] Artemisinin combination therapy reduced parasitaemia at the regional, but not at the national scale in Burkina Faso,[54] suggesting that insecticide-treated nets and indoor residual spraying are more effective at scale. One study found that such interventions had stronger effects on malarial burden relative to climatic changes,[50] but another found the opposite effect.[49]

Co-benefits of mitigation

Global warming causes many adverse health outcomes from pregnancy through to adulthood.[2] Studies evaluating the co-benefits of climate change mitigation through greenhouse-gas reduction were the most common compared to all other adaptation themes. These included modelling studies investigating a range of child-health outcomes under various mitigation scenarios. The evidence was consistent — reduction in air pollution had benefits for child health, including better respiratory outcomes,[56-61] fewer adverse birth outcomes,[57] fewer life years lost,[62] and lower infant mortality.[57,61,63] Only one study on the 2005 Clean Air Act in South Korea found no impact on infant mortality.[64]

Following Shea *et al.* (2020) who provided per-case monetary estimates of annual avoided health costs,[65] several studies calculated the avoided financial losses following mitigation. A study on the U.S. regional greenhouse-gas initiative reported estimated savings of US$191 million to US$350 million through reductions in childhood asthma, preterm births, and low birth weights if the initiative successfully meets its targets.[56] A transportation climate-policy scenario in New York City, U.S. estimated saving US$22 million due to avoided asthma cases and adverse birth outcomes.[57] However, policies promoting public and active transport must be accompanied by safety

improvements of walking and cycling environments, because children might become more exposed to road injury and extreme temperatures.[66] Only one study evaluated cost benefits outside the U.S. — a 2015 study in Europe reported that the economic value of health benefits would offset at least 85% of the additional cost of implementing mitigation policies.[62] National policies targeting reductions in air pollution have been successful and cost-effective in high-income countries, and the potential for similar effective strategies in low- and middle-income countries to improve health outcomes without reducing economic growth are vast.[67]

Reducing air pollution via increased green space was another strategy with considerable co-benefits, being associated with higher birth weights[15,68,69] and reduced incidence of preterm birth.[68,70] Links between green space and infant mortality were unclear[71]; however, a French study suggested that variation in the amount of greenness might partially explain spatial distributions of infant mortality.[72]

Discussion

While still sparse, largely qualitative, and incomplete, the available literature reveals that the main interventions proposed for reducing the negative effects of climate change on child health included heat interventions, changes to water, sanitation, and hygiene protocols, disaster-risk management, modifications to promote respiratory health, promotion of mental health, and policies to reduce the incidence of vector-borne disease. Interventions that consistently had positive effects on child health outcomes included cash transfers to pregnant women,[13] rainwater collection,[30] and green space to reduce the incidences of low birth weight.[15,68-70] Providing access to green space further improved heat-adaptation behaviours and physical activity in school children.[14,19] Heat-related morbidity was reduced by moving hospital maternity wards to cooler locations[24] and implementing preseason sport guidelines.[27] Household-level livelihood diversification reduced the prevalence of being underweight,[32] and retrofitting buildings with insulation and administering pneumococcal conjugate vaccines reduced asthma and cold-related pneumonia, respectively.[43-45] Providing insecticide-treated nets,[49,50,52-54] indoor residual spraying,[53,55] and artemisinin combination therapy[54] reduced the incidence of malaria and associated mortality. Classroom-based interventions were generally effective at increasing knowledge of health-adaptation behaviours, risk awareness, mental well-being, and confidence in school-aged children.[25,37-40]

Limitations

Of the 58 studies, only four were randomised controlled trials and all had limitations due to their use of surrogate outcomes (risk awareness and behavioural outcomes) and/or convenience sampling. In addition, 49 studies were retrospective and only nine were prospective. The long-term efficacy of interventions remains unclear due to this lack of prospective, post-implementation monitoring. We excluded all studies published in a language other than English. The heterogeneity of the interventions, target demographics, and outcomes limited their suitability for comparison and meta-analysis.

Recommendations

Where possible, we recommend that prospective studies be done to improve the quality of evidence and allow for the longevity of each intervention to be evaluated, through additional post-implementation data collection. Considering the sustainability and long-term impacts of interventions is important to make effective policy decisions. We acknowledge the limitations in that certain climate risks and outcomes can only be ethically studied retrospectively.

For studies that target populations < 19 years old, we recommend that they stratify their outcomes by age group to account for age-specific responses to interventions. In general, studies should explore a wider suite of health outcomes, aligning these with other published studies to provide a more cohesive evidence base. Nevertheless, interventions should account for their target populations' unique characteristics, which will inherently reduce their applicability to other contexts. In short, more studies are needed so that interventions can be compared to others targeting similar populations.

Specific recommendations have been made regarding each theme. *Heat:* Of the studies that evaluated national heat-warning systems, the heterogeneity of responses, heat-wave warning thresholds, and climates in each country highlight a need for information on country-specific factors leading to successful warning systems. Green space should be explored further because it provides additional co-benefits as a mitigation strategy. *Water, sanitation, and hygiene:* Rigorously designed and controlled studies that consider cost-effectiveness are needed to provide quantitative evidence for the policy design of water, sanitation, and hygiene services.[28] Cost-effectiveness is an important consideration given that the burden of food- and water-borne diseases is predominantly borne by children living in low- and middle-income countries.[29] National-level interventions, such as national poverty-reduction programs, should be prioritised because they might be more effective at targeting climate change-related disease burden at scale.[28] *Food insecurity and undernutrition*: Given the

multidimensionality of poverty, more evidence is needed on region-specific, sustainable interventions adapted to the needs of communities. *Disasters and extreme weather events*: Studies are needed on a wider range of disasters, because existing studies mainly focus on floods. Studies should quantitatively evaluate health outcomes directly, instead of assessing surrogate outcomes or qualitatively describing the success of programs. Interventions to address the short-term outcomes of disasters, such as injuries and deaths, should be evaluated. There is also a need for studies on interventions addressing longer-term impacts, such as increased communicable disease burden due to the damage of infrastructure. *Respiratory illnesses*: Given the evidence for positive effects of green space on pregnancy outcomes,[15,68-70] more prospective studies are needed to evaluate potential benefits on children's respiratory health following birth. Additionally, interventions should be designed to target a wider range of respiratory illnesses, such as pneumonia, as evidence on illnesses other than asthma is lacking. *Mental health*: More robust research designs are required to quantify the impacts of mental health interventions for young people in response to climate change. A wider suite of specific mental health outcomes, instead of general well-being, should be evaluated. Depression, anxiety and post-traumatic stress are the most common impacts, with children being especially vulnerable.[47] *Vector-borne diseases*: Studies should examine the relative impacts of climate variability and existing interventions to assess whether they are sufficient to adapt to the changing climate. Additionally, no studies on dengue met our inclusion criteria despite the global upsurge in cases and spread into previously unaffected regions.[73] *Co-benefits of mitigation*: Because most studies in this area have been done in high-income countries,[67] more studies focusing on low- and middle-income countries are needed for comparison. This is especially pertinent given the higher relative vulnerability of people in low- and middle-income countries to climate change, and the promising, although limited, evidence available on the cost-effectiveness of mitigation policies.[62] There is evidence that reductions in air pollution might reduce infant mortality in African countries,[5] highlighting the potential for similar benefits in other low- and middle-income countries.

Conclusion

Overall, literature available on this topic was scarce, meaning that policy development is largely informed by opinion rather than evidence. Therefore, the evidence base of child-health interventions for climate change is inadequate to drive effective decision-making for policy development. Even the currently available evidence is weakened given its reliance on mostly retrospective, observational study designs and surrogate outcomes. Of the 58 studies, only four were randomised

controlled trials and 49 were not prospective. Additionally, the heterogeneity of interventions, demographics, and health outcomes measured makes comparison and generalisation difficult. Nonetheless, several interventions positively influenced child health, with air pollution reduction via mitigation consistently improving health outcomes. Other interventions included cash transfers, rainwater collection, green space, maternity ward relocation, sport guidelines, livelihood diversification, retrofitting buildings with insulation, pneumococcal conjugate vaccines, insecticide-treated nets, indoor residual spraying, artemisinin combination therapy, and classroom sessions about climate change.

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Appendix A

Theme	Paper	Location	Intervention	Child health outcome	Demographic	Study type
Heat	Lanza et al. (2021)	Texas, USA	Green features in school parks	Heat index (F), children's interaction with green features (%)	8-10y	Cross-sectional
	Wu et al. (2020)	Shanghai, China	Heat warning system: alert sent to residents with "Yellow" (35C for three consecutive days), "Orange" (37C) or "Red" (40C)	Amount and morbidity of heat-related illnesses, mortality	0 to <19y	Cross-sectional
	Kakkad et al. (2014)	Ahmedabad, India	Move maternity ward to cooler floor (top floor) in hospital	No. of neonates admitted to NICU with heat diagnosis	0-28 days	Cross-sectional
	Heo et al. (2019)	Korea	Heat wave warning system: opening shade shelters at night and on weekends/holidays, health worker dispatch to vulnerable subpopulations, 2-5pm break times for young students in schools	All-cause mortality, cardiovascular mortality, respiratory mortality DD	0 to <19y	Time-series
	Kerr et al. (2019)	USA	NATA-IATF guidelines (2009) to reduce exertional heat illness in U.S. high school athletes participating in preseason sports activities: gradual acclimatisation for 2 weeks, limit practices to 3hrs	incidence rate ratios for exertional heat illness with/without mandate	13-18y	Statistical modelling
	Nitschke et al. (2016)	Adelaide, Australia	Heat warning system: general heat health advice before summer; public alerts and advice through media; continuous review of emergency, ambulance and other clinical response capabilities in the health sector; provision of free support calls to registered vulnerable people	ambulance call-outs; hospital admissions; emergency department presentations; mortality	0-4y; 5-14y	Case series
	Lanza et al. (2023)	Texas, USA	Green space and shade sail structures in schoolyards	% physical activity, % shade behaviour during recess time	8-10y	Prospective cohort
	Sun et al. (2020)	California, USA	Green space	Preterm birth risk	Pregnant women	Cross-sectional
	LaPointe et al. (2024)	Ghana	cash transfers to pregnant women	low birth weight prevalence	0-36mo	Cross-sectional
	Clemens et al. (2022)	Ontario, Canada	Ontario's Heat Warning and Information System (clear heat warnings, education to at-risk groups and healthcare providers, opening cooling stations, promoting air-conditioning use, adjusting public school programming, providing targeted outreach	rate of emergency department visits for heat-related illness	<18y	Time series
	Li et al. (2022)	Dongtai, China	Health education activities program to respond to heatwaves and climate change	knowledge, attitude and practice survey scores before and after intervention	8-11y, parents	Randomised controlled trial
	Yang et al. (2024)	Shanghai, China	Greenness exposure during pregnancy	birthweight; birthweight Z-score; small-for-gestational age; large-for-gestational age	Pregnant women	Cross-sectional
	Adebayo et al. (2020)	USA	Information brochure (narrative versus didactic)	knowledge of maternal and child health risks associated with climate change; perceived risk to self and pregnant women in general; affective assessment of climate change; self-efficacy to reduce the maternal and child risks of climate change; intention to engage in risk-	Pregnant women	Randomised controlled trial

				reducing actions; subsequent information-seeking behaviour		
	Kabisch et al. (2017)					Systematic review
	Casey et al. (2016)	Pennsylvania, USA	Green space in buffers of 250m and 1250m around the maternal place of residence	Term birth weight, gestational age, preterm birth, low 5-min Apgar score	neonates	Cohort
	Dadvand et al. (2012)	Barcelona, Spain	Green space in buffers of 100m and 500m around the maternal place of residence	Birth weight, gestational age at delivery	neonates	Cohort
WASH	Da Mata et al. (2023)	Brazil	First Water Cisterns program: tanks built next to houses to store rainwater from roof catchments/gutters	birth weight, foetal growth rate, weeks of gestation, low birth weight	in-utero	Cohort
	Hutton & Chase (2016)					Review
	Cisse (2019)					Review
Food insecurity and undernutrition	Bailey et al. (2019)	Eswatini	Planting drought/heat resistant crops, conservation farming, beekeeping, chicken husbandry, selling natural resources, selling crafts, other salaried off-farm work, participating in local organisations	weight-for-height, height-for-age, weight-for-age	<5y	Cross-sectional
	Walton et al. (2023)	Niger	Food security and nutrition policies/programs	BMI, anaemia during pregnancy, iron folate supplementation coverage for women; underweight, stunting, wasting trajectories from birth to 5y	women; 0-5y	Time-series
	Dyngeland et al. (2020)	Brazil	Brazil's Zero Hunger social protection programs: targets small-scale family farmers. Low interest agricultural credits and access to price-controlled markets. National School Feeding program (free school meals, promotes use of produce from family farms). Monthly cash transfers for families in poverty, conditional on child school attendance and participation in family health checks and vaccination programs.	proportion of underweight infants and children 12-24mo; infant mortality	12-24mo; <1y	Time-series
	Santoso et al. (2021)	Tanzania	participatory, experiential-based learning and theater about sustainable agriculture practices, nutrition, women's empowerment	children's dietary diversity score (0-7 food groups); height-for-age; weight-for-height; stunting rates; wasting rates	<1y	Cluster randomised trial
Disasters and extreme weather events	Zhong et al. (2021)	Sichuan, China	Three-year school-based, social network-based flood disaster education	flood disaster awareness, health-related behaviour (e.g. washing hands)	8-12y	Cross-sectional
	Purno et al. (2023)	Bangladesh	Post-flood deployment of midwives at local health facilities	Qualitative	Pregnant women	Case-series
	Proulx & Aboud (2019)	Sumba, Indonesia	Disaster risk reduction and resilience education	disaster risk reduction-related knowledge test score	5-6y	Quasi-experimental
	Basilio et al. (2022)					Review

	Amri et al. (2018)					Review
	Coombe et al. (2015)					Systematic review
Respiratory diseases	Karakas et al. (2023)	England	Energy efficiency retrofits in schools	Incidence asthma rates	5-16y	Statistical modelling
	Chapman et al. (2009)	New Zealand	Retrofitting houses with insulation	respiratory hospitalisations; days off school	<19y; 6-11y, 12-18y	Cluster randomised trial
	Tao et al. (2022)	Matlab, Bangladesh	pneumococcal conjugate vaccination	hospitalisations for childhood pneumonia	<1y, 1-5y	Interrupted time-series and case-crossover
	Pilat et al. (2012)	Texas, USA	Green space, canopy cover	Childhood asthma rates	<17y	Statistical modelling
Mental health	McGill et al. (2023)	New South Wales, Australia	Post-bushfire counselling	Qualitative	unspecified	Commentary
	Bikomeye et al. (2021)		Green spaces in schoolyards			Systematic review
Vector-borne disease	Kayentao et al. (2018)	Mali	Insecticide-treated nets, intermittent preventive treatment in pregnancy, improved malaria case management	all-cause mortality; prevalence of morbidities (parasitaemia and severe anaemia)	<5y	Time-series
	Lubinda et al. (2021)	Zambia	Long-lasting insecticide nets, indoor residual spraying	malaria incidence	<5y	Statistical modelling
	Traoré et al. (2024)	Burkina Faso	Insecticide-treated nets, artemisinin-based combination therapies, indoor residual spraying, chemoprophylaxis	Parasitaemia prevalence	<5y	Time-series
	Ngomane & De Jager (2012)	South Africa	Indoor residual spraying	Malaria incidence rates, case fatality rates	0-14y	Time-series
	Nyawanda et al. (2023)	Kenya	Bed nets	Malaria incidence	6-59mo, 5-14y, <15y	Time-series
	Ssempiira et al. (2018)	Uganda	Insecticide-treated nets, artemisinin-based combination therapies	Malaria incidence	<5y	Time series
Mitigation	Shea et al. (2020)		Reducing fossil fuel combustion	per-case monetary estimates for preterm birth, term low birth weight, asthma, autism spectrum disorder, ADHD, loss of an IQ point		Review
	Perera et al. (2020)	USA	U.S. regional greenhouse gas initiative	change in incidence, economic valuation of change in incidence for preterm birth, term low birth, ASD, asthma	0-18y	Statistical modelling

Coomes et al. (2022)	New York City, USA	Transportation and Climate Initiative (cap-and-invest program for gasoline suppliers)	infant mortality, preterm birth, term low birth weight, child asthma incidence, child asthma hospital admissions, emergency department visits, asthma exacerbations not requiring medical care, lower respiratory infection, lower respiratory symptoms, acute bronchitis, ASD	0-1y (PTB, TLBW, infant mortality); 5-17y (asthma incidence, asthma exacerbations, asthma HA and ED visits, LRS, LRI)	Statistical modelling
Bell et al. (2006)	Santiago, São Paulo, Mexico City	Lower projected annual average PM10 concentrations for Mexico City, Santiago, and São Paulo by 5.2, 4.6, and 5.2 mg/m3; Lower annual average daily 1h max. ozone concentration by 11.0, 2.7, and 4.2 ppb in the year 2002 for Mexico City, Santiago, and São Paulo, respectively	total no. health effects avoided (infant mortality, children's medical visits, children's hospital admissions)	<1y (mortality); 3-15y (children's medical visits); <13y (children's hospital admissions)	Statistical modelling
Schucht et al. (2015)	Europe	Reducing PM2.5 and ozone concentrations to limit global temp. increase to 2C by the end of this century	infant mortality; respiratory medication use; lower respiratory symptom days	0-1y (mortality); 5-14y	Statistical modelling
Li & Crawford-Brown (2011)	Bangkok, Thailand	PM-oriented vehicle inspection and maintenance program targeting all diesel-fueled vehicles in Bangkok area (25% total PM10 reduction from baseline)	acute infant mortality	0-1y	Statistical modelling
Lee et al. (2007)	Busan, Korea	reduced traffic flow for 14 consecutive days, reducing air pollutant levels by 1-25%	hospital admissions for childhood asthma	<15y	Time-series
Komisarow & Pakhtigian (2021)	Chicago, USA	coal-fired power plant closures	emergency department visits for asthma-related conditions	0-4y	Statistical modelling
Tanaka (2015)	China	Two Control Zone policy: power industries reduce emissions, install new pollution control technologies, shut down small inefficient power plants	infant mortality rate	<1y	Statistical modelling
Lee et al. (2018)	South Korea	2005 South Korea Clean Air Act: tightened pollution monitoring for diesel emission cars in Seoul and surrounding areas	infant mortality	<1y	Time-series
Jones & Goodkind (2019)	New York City, USA	One million new trees planted; approx. 20% increase in urban forest cover	Preterm birth, low birth weight	neonates	Statistical modelling
World Health Organisation (2011)					Review
Schraufnagel et al. (2019)					Review
Ebisu et al. (2016)	Connecticut, USA	Green space within 250m from residence	Low birth weight, small for gestational age	neonates	Statistical modelling
Hystad et al. (2014)	Vancouver, Canada	Green space in buffers of 100m and 250m around residence	Term birth weight, preterm birth, gestational age	neonates	Statistical modelling
Kihal-Talantikite et al. (2013)	Lyon, France	Share of green space in total area of census block	Infant mortality	<1y	Statistical modelling

	Padilla et al. (2016)	Nice, France	Land cover data-based natural area (parks, forests, gardens…); share of green spaces and per capita green space	Infant and neonatal mortality risk	<1y	Statistical modelling

Appendix B

Citation	Quality of evidence	Factors that increase quality	Factors that reduce quality
Lanza et al. (2021)	Very low		Surrogate outcomes (Heat index, children's interaction with green features) Convenience sampling; failure to adequately control confounding; flawed measurement of outcome.
Wu et al. (2020)	Moderate		Quasi-experimental, leading to risk of bias
Kakkad et al. (2014)	Very low		Failure to adequately control confounding.
Heo et al. (2019)	Moderate		Quasi-experimental, leading to risk of bias
Kerr et al. (2019)	Moderate	Large magnitude of effect: IRR<0.5	Participant-reported incidence of exertional heat illnesses; convenience sample used in dataset
Nitschke et al. (2016)	Very low		Case-series leading to risk of bias; failure to adequately control confounding
Lanza et al. (2023)	Very low		Surrogate outcomes (physical activity, shade-seeking behaviour) Convenience sampling, failure to adequately control confounding
Sun et al. (2020)	Very low		For certain heatwave definitions, there were wide CIs for the effects of green space exposure on relative risks of preterm birth, which suggested either a positive or negative relationships was possible (inconclusive). However, it should be noted that most heatwave definitions had narrower CIs. Failure to adequately control for confounding variables, including indoor and outdoor exposure heterogeneity, health status and individual activity patterns of participants

LaPointe et al. (2024)	Very low		Out of the whole sample, only a small sub-sample had complete information on birthweights available to be used in analysis, so statistical methods were used to impute the missing birthweights; failure to adequately control for confounding climate variables
Clemens et al. (2022)	Low		Failure to adequately control for time-varying confounding. This was not considered sufficient to downgrade evidence quality to very low.
Li et al. (2022)	Low	Knowledge and attitude scores increased in all students regardless of the confounding variable of age; however, age was a confounder for practice scores. The evidence quality level was not upgraded.	Indirectness of evidence: surrogate outcomes (knowledge, attitude and practice scores) Convenience sampling
Yang et al. (2024)	Very low		Loss to follow-up for 15 992 women who lacked birth records; failure to control for community variables, which may have led to issues with spatial autocorrelation
Adebayo et al. (2020)	Very low		Surrogate outcomes (knowledge, attitude) Limitations in study design: convenience sampling; failure to adequately control confounding; patient-reported outcomes; lack of longitudinal follow-up Small sample size
Casey et al. (2016)	Low		Some limitations of data sources may have caused issues in the control of confounding variables. However, other variables were used as a proxy for missing data, and known confounders were appropriately controlled for, so the evidence quality level was not downgraded.
Dadvand et al. (2012)	Low		Unexplained heterogeneity of results in subpopulation of pregnant mothers with secondary-school education. However, the effects were small and of borderline significance. The evidence quality level was not downgraded.
Da Mata et al. (2023)	Moderate	Large magnitude of effect: the intervention was associated with increases in birth weight that were greater than others in previously published literature. It was also highly cost-effective.	
Bailey et al. (2019)	Low		Use of patient-reported outcomes on whether household adaptation strategies were successful. However, the study recognised this as an imperfect indicator and so directly measured child weight and height. The evidence quality was not downgraded.

Walton et al. (2023)	Moderate		Quasi-experimental, leading to risk of bias. No comprehensive data exists on implementation successes, challenges and outcomes of all of the nutrition and food security programs studied; difficult to ascertain attribution to nutritional outcome improvements. However, the study reports that the findings suggest a contribution to these improvements given the programs' multiplicity, diversity of actors, financing and targeting of vulnerable populations. The evidence quality was not downgraded.
Dyngeland et al. (2020)	Moderate		Quasi-experimental, leading to risk of bias
Santoso et al. (2021)	Moderate		Lack of blinding due the participatory nature of the intervention. Use of surrogate and patient-reported outcomes (children's dietary diversity). However, child anthropometric outcomes were also measured, so evidence quality was not downgraded for this reason.
Zhong et al. (2021)	Very low	All plausible confounding would reduce the demonstrated effect. However, given the limitations in design and inadequate follow-up, the evidence quality is very low.	Self-reported outcomes. However, the Propensity Score Matching Method helped to eliminate the potential of systematic overstatement or understatement due to bias. Evidence quality was not downgraded for this reason. Surrogate outcomes (knowledge, risk perception, health-related behaviour). Inadequate follow-up: a new sample from the same age group was selected instead of following the original sample.
Purno et al. (2023)	Very low		Case-series with no control group. Use of surrogate outcomes (qualitative observations, no. of services delivered) – unclear whether maternal health outcomes were affected.
Proulx & Aboud (2019)	Very low		Quasi-experimental leading to risk of bias; use of self-reported outcomes; use of surrogate outcomes (knowledge).
Karakas et al. (2023)	High	All plausible confounding did not reduce the demonstrated effect.	
Chapman et al. (2009)	Moderate		Use of self-reported outcomes (GP visits, days off school and work)
Tao et al. (2022)	Moderate		Quasi-experimental, leading to risk of bias

Pilat et al. (2012)	Low		Parent-reported outcomes of asthma incidence in their children; small sample sizes
McGill et al. (2023)	Very low		Commentary with lack of control group; qualitative data only; unclear age demographic of sample.
Kayentao et al. (2018)	High	Malaria control interventions contributed to observed decline in all-cause mortality of children under 5, despite plausible confounders of climate, continued high parasitaemia prevalence and political instability.	Nationally representative data was lacking for most of the evaluation period, lack of reliable baseline data
Lubinda et al. (2021)	Moderate		Quasi-experimental, leading to risk of bias
Traoré et al. (2024)	Low		The data from the surveys used were carried out during the early dry season and dry season; the difference in transmission seasons may have led to overestimates in reduction in malaria prevalence. owever, this was not considered a sufficient enough limitation to downgrade evidence quality to very low.
Ngomane & De Jager (2012)	Very low		Failure to adequately control for confounding variables, including socioeconomic status, effects of other preventive interventions and changes in vector population.
Nyawanda et al. (2023)	Low		Did not adjust for the potential impact of community case management initiated in 2013. However, the authors acknowledge that two other studies evaluating intermittent mass testing and treatment in the same region observed similar outcomes for the intervention and control, suggesting that the exclusion of case management did not bias their findings. Evidence quality was not downgraded.
Ssempiira et al. (2018)	Moderate	Large magnitude of effect of insecticide-treated nets: IRR<0.5	
Perera et al. (2020)	Moderate		Quasi experimental, leading to risk of bias. Calculations of avoided costs are likely underestimates, due to reliance on the cost of illness and lack of consideration of long-term costs; did not consider impacts of PM2.5 reduction. These were not considered sufficient to downgrade evidence quality to low.
Coomes et al. (2022)	Moderate		Quasi experimental, leading to risk of bias. Underestimation of between-neighbourhood inequality in air pollution exposure due to lack of finer-scale data. This was offset by incorporating neighbourhood or census tract-level data on baseline incidence and background risk factors. Evidence quality was not downgraded.

Bell et al. (2006)	Moderate		Quasi experimental; concentration-response functions for PM were derived from studies outside the cities of interest.
Schucht et al. (2015)	Moderate		Quasi experimental, leading to risk of bias. Benefits assessment was conservative and likely an underestimate – this was not considered sufficient to downgrade evidence quality to low.
Li & Crawford-Brown (2011)	High		Some uncertainty in key assumptions used – but not sufficient to downgrade evidence quality.
Lee et al. (2007)	Low		Unexplained inconsistency of seasonal variation in asthma hospitalisations with previously published studies. This was not considered sufficient to downgrade evidence quality to very low.
Komisarow & Pakhtigian (2021)	Moderate		Quasi-experimental, leading to risk of bias
Tanaka (2015)	High	All plausible confounding did not reduce the demonstrated effect.	Quasi-experimental, leading to risk of bias
Lee et al. (2018)	Moderate		Quasi-experimental, leading to risk of bias
Jones & Goodkind (2019)	Moderate		Quasi-experimental, leading to risk of bias
Ebisu et al. (2016)	Moderate		Quasi-experimental, leading to risk of bias. Did not adjust for potential changes in mothers' addresses throughout pregnancy, and ambient air pollutants other than PM2.5. This was not considered sufficient to downgrade the evidence quality to low.
Hystad et al. (2014)	High	All plausible confounding (air pollution and noise exposures, neighbourhood walkability, park proximity) did not reduce the demonstrated effect.	Quasi-experimental, leading to risk of bias.

Kihal-Talantikite et al. (2013)	Moderate		Quasi-experimental, leading to risk of bias
Padilla et al. (2016)	Low		Quasi-experimental, leading to risk of bias. Failure to adequately control confounding (birthweight, gestational age, mother's age, parity of the newborn, maternal lifestyle behaviours); small study population