





Interventions to reduce the effects of air pollution and of extreme heat on maternal, newborn, and child health outcomes: a mapping of the literature

Joe Strong¹ ,
Rachael Barrett¹,
Ziyaad Surtee¹,
Maggie O'Hare¹,
Francesca Conway² ,
Anayda Portela² 

¹Department of International Development, London School of Economics and Political Science, Houghton Street, London, UK

²World Health Organization Department of Maternal, Newborn, Child and Adolescent Health and Ageing, Geneva, Switzerland

Background There is an increasing awareness of the ongoing and projected impacts of air pollution and of extreme heat on maternal, newborn, and child health (MNCH) outcomes, showing significant short and long-term health problems. There is a dearth of information available for policy makers on interventions that have been implemented to reduce the impact on MNCH, impeding the integration of action into health planning. This paper presents an inventory of interventions aimed at reducing the effects of these two climate hazards on MNCH.

Methods We conducted a scoping review of articles published in three databases and grey literature to identify and map interventions implemented to address the impact of air pollution and/or extreme heat on MNCH. Items were included if published between January 2016 and November 2022, regardless of language, and as this is an inventory, regardless of if the intervention was evaluated. Over 32 700 journal items were reviewed for inclusion and a sample of grey literature from web-based searches.

Results A final inventory of 76 items were included. Interventions identified were primarily based in the Global North (n=51), with the largest proportion in the USA (n=17), while 32 items were based in the Global South. Fifty-seven items focused on air pollution, 18 on extreme heat, and one on both. Interventions were categorised in four adapted socioecological components: (i) individual and household interventions (n=30), (ii) community and service interventions (n=18), (iii) structural interventions and urban landscape interventions (n=15), (iv) policy interventions (n=16). Most items were focused on child health outcomes (n=65); 61 items were evaluated.

Conclusions This scoping review maps interventions implemented and proposes a categorisation of these to initiate reflections and dialogue on what has been done and how to start building an evidence base. The review also highlights gaps in interventions and the knowledge base, with most interventions implemented to address air pollution, in the Global North and most addressing child health need. As country programmes seek to address the impact of climate change on MNCH, additional efforts are needed to better understand what has been done, document lessons learned, agree on common outcome measurements and feasible study designs for evaluation to start building the evidence base.

Correspondence to:

Anayda Portela
World Health Organization
Department of Maternal, Newborn,
Child and Adolescent Health and
Ageing
Avenue Appia 20, Geneva
Switzerland
portelaa@who.int

In 2023, the World Health Organization, the United Nations Population Fund, and the United Nations Children's Fund launched a call to action for key partners in health to work together to raise awareness and commit to addressing the risks of climate hazards on maternal, newborn, and child health (MNCH) [1] (Box 1).

Box 1.

We use the word ‘women’ throughout this article. This is used as it is reflected in the reports and articles included. The word women is used for anyone who identifies as a woman regardless of sex assigned at birth. We recognise that there are other gender-diverse individuals who do not identify as women but have critical MNCH needs. The intention is not to exclude their experiences but rather to reflect the current lack of data on their experiences.

Studies and reports increasingly demonstrate how the effects of the climate crisis are not uniform across populations, reflecting social and structural determinants of health that are shaped along axes of discrimination and inequality [2]; these effects will have a significant impact on vulnerable populations, including pregnant women, newborns, and children [3,4]. The Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change emphasised that women – particularly pregnant women – and children were among the most vulnerable to the climate crisis [5,6].

Both air pollution and extreme heat affect health. The two hazards are interlinked and exacerbate the effects of each other on the climate crisis [7,8]. Projected emission scenarios suggest surface temperatures may rise between 1.1 and 6.4°C in some parts of the world by 2100 [9], and air pollution is increasingly reaching hazardous levels, particularly in large metropolises in the Global South [10]. In addition to being individually significant drivers of adverse health outcomes, the effects of these climate hazards can intersect with and compound existing inequalities and structural disadvantages, for example women’s gendered labour burdens, including physical activities such as household chores and care work [5,11].

Studies highlight how exposure to ambient air pollution among pregnant women and infants increases associated respiratory conditions and is associated with adverse immune, neurological, and cardiometabolic outcomes [12]. Further, exposure to air pollution during pregnancy can be associated with development of pregnancy complications and of adverse birth outcomes such as low birth weight and preterm birth [13,14]. For children, air pollution can lead to short- and long-term impacts on health outcomes [15], including respiratory diseases and a potential impact on cognitive health [16].

Extreme heat can have a variety of potentially significant effects on pregnancy outcomes [17,18]. Various observational studies have reported an association between heat exposure in the weeks prior to birth and increased risks of preterm or stillbirth [19,20]. Newborns are especially vulnerable to extreme heat, due to impaired thermoregulation as a result of immature temperature control systems, which can cause acute and life-threatening health conditions [4]. Moreover, extreme heat can affect food systems, impacting the nutritional status of pregnant and breastfeeding women and children [21,22].

Existing reviews emphasise the epidemiological associations between the climate crisis and adverse MNCH outcomes, highlighting that most available evidence comes from Global North contexts [23–26]. A systematic review of the impact of the high temperatures on birth outcomes found an association between high temperatures and preterm birth, low birth weight, and stillbirths [27]. A meta-analysis investigating maternal exposure to air pollution found that prenatal exposure to major air pollutants during the entire pregnancy can increase the risk of low birth weight [28]. A scoping review that focused on climate change and emergency care in the African continent highlighted evidence of the heightened risks that particularly children and women faced as a result of the climate crisis [29].

The growing body of evidence illustrates the associations between exposures to climate hazards and adverse MNCH outcomes. The evidence particularly on exposure to high temperature or air pollution highlights the essential need to develop interventions that can reduce the effects of climate-related exposures and of air pollution on MNCH. While it is important to understand the different risks faced for MNCH, it is also important to identify evidence-informed actions that can be taken. However, there is a lack of information available in the literature on those interventions that could safeguard MNCH from these two climate hazards. In order to better understand what has been implemented, we conducted a scoping review to establish an inventory of implemented interventions to reduce the impact of exposure to extreme heat and air pollution on MNCH.

METHODS

Our review was developed to answer the following research question: what interventions are currently being implemented to address the effects of air pollution and extreme heat on MNCH? To answer this, we conducted a scoping review to map the existing literature, adapting the framework developed by Arksey and O'Malley [30], to create an inventory of interventions that aimed to reduce the effects of extreme heat and/or air pollution on MNCH. A scoping review was chosen as the most appropriate method for the aim to map existing work and identify gaps [31]. A review protocol was published and includes further details of the rationale and methods [32].

We searched both the grey and published literature. We included any document which described an intervention, regardless of whether the intervention had been evaluated or not. The selected timeframe reflects publications after December 2015 (signing of the Paris Agreement at COP21) until the time of the search conducted for this review.

Three relevant databases were searched for published literature: Ovid Medline, EMBASE, and Global Health. Articles were de-duplicated and then screened based on title and abstract against the inclusion/exclusion criteria, using Covidence (Table 1). Potentially relevant articles were then reviewed based on the full text (Table S1 in the [Online Supplementary Document](#)).

Table 1. Inclusion/exclusion criteria

Inclusion
Published between January 2016 and December 2022
Specific to pregnant and postpartum women (six weeks after birth), newborn (birth to 28 d of age) or children (one month up to and including aged 10), parents with newborns or children up to age 10, or a disaggregated sub-sample in a broader intervention for the general population
Focused on interventions implemented to reduce the effects of extreme heat and/or air pollution with or without an evaluation
Any published or grey literature document reporting on the topic of interest including peer-reviewed literature or conference abstracts, editorials, or commentaries published in academic journals or reports available on web sites
Any geographic location
Published in any language
Exclusion
No clearly disaggregated sub-sample of pregnant or postpartum women, newborns, and / or children
Interventions aimed to mitigate air pollution where the specified pollutant was not a major health damaging pollutant
Interventions aimed to mitigate air pollution where the specified pollutant was not related to outdoor pollution (limited to indoor air pollution, i.e. cooking stoves)
No clearly described intervention activity; associations between green/blue space and climate hazard exposure were not considered an intervention
Medical treatment protocols
Narrative / literature / scoping / systematic reviews

RB, ZS, MOH, and DM screened articles; FC then re-screened 10% of the excluded articles from the title and abstract screening for quality assurance. JS reviewed the final inventory for a second round of quality checks. Any discrepancies were discussed with all authors to decide whether to include or exclude an article.

The database searches were supplemented by a search for grey literature including of web pages of organisations known to have work related to climate change and other UN agencies and implementing partners with work on MNCH. A call for documents by email was also sent to World Health Organization (WHO) partners; these were screened by RB, ZS, MOH, and DM. The web search was conducted by KM and double checked by AP, FC, and JS.

A template was developed for data extraction and was tested against ten articles (Table S2 in the [Online Supplementary Document](#)). The development of the template drew on existing work for a rapid scoping review [33]. RB, ZS, MOH, DM, and KM conducted data extraction; JS, AP, and FC reviewed. No quality assessment was conducted as this was a mapping of the literature and could potentially include items that were not evaluated [31].

For the purpose of this scoping review, interventions are treated as one item where they are described and/or evaluated collectively (e.g. an article assessing the combined effects on air pollution of a series of policies over time). For journal articles, this resulted in each article being treated as one item. For grey literature, where case studies were reported separately and were distinct from one another, one report could include multiple items. We followed the PRISMA-ScR guidelines in reporting our findings [34].

RESULTS

Figure 1 shows the number of items identified in the published and grey literature. A total of 62 interventions were included from journal-based articles, and 14 interventions were included from supplementary grey literature (identified in eight reports). The final inventory includes 76 items from 70 sources, details of each included item are presented in Tables S2–3 in the **Online Supplementary Document**.

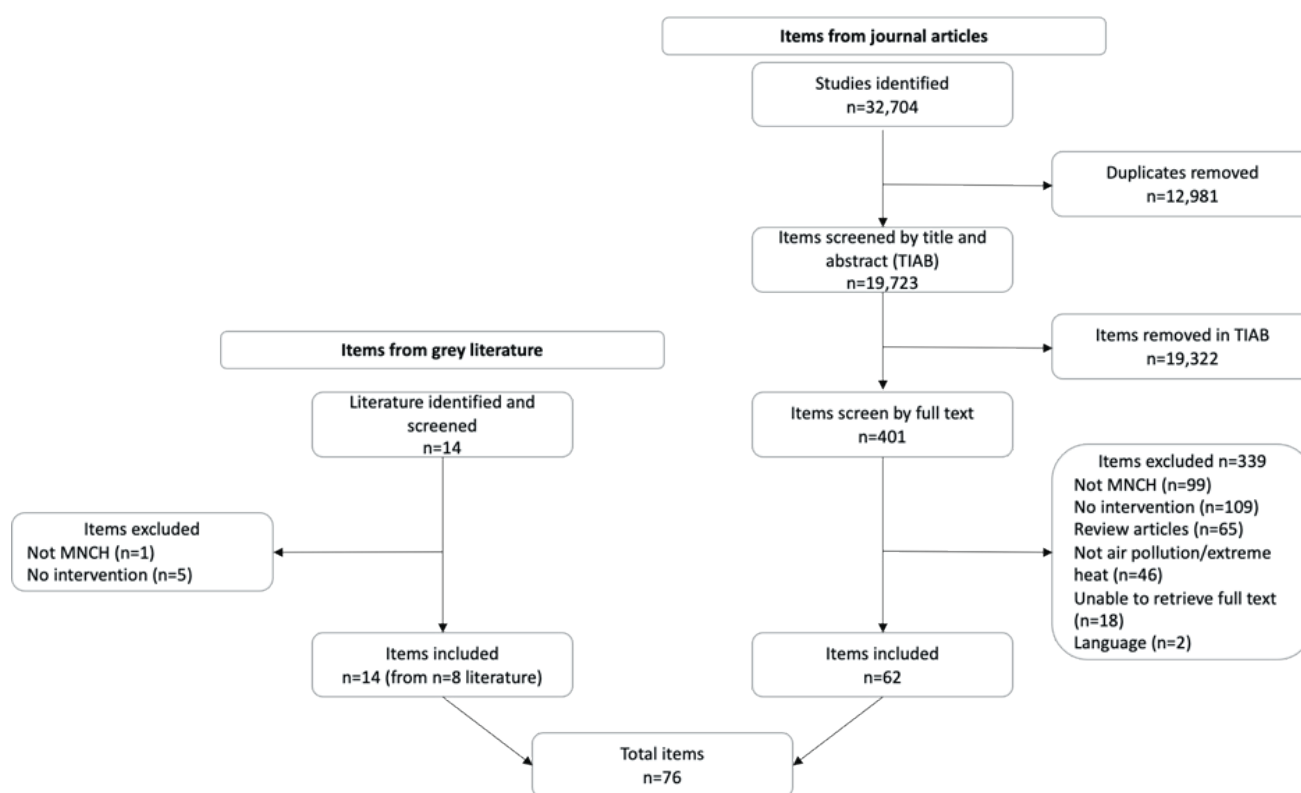


Figure 1. Flow diagram of included items.

Table 2 summarises key characteristics of the included interventions. Interventions were categorised into four levels.

The majority of included items focused on air pollution ($n=57$, 75%); 18 (23.7%) focused on extreme heat (**Table 2**) and one item focused on both air pollution and extreme heat. After extraction, we categorised the interventions into four levels, using an adapted socio-ecological framework [35,36]:

- individual and household interventions, including interventions aimed directly at the populations of interest or their families
- community and service interventions including interventions designed to impact on community actors, teachers, health workers, etc.

- structural interventions and urban landscape including interventions designed to address buildings like schools or health facilities and urban landscapes
- policy interventions, designed to ensure policies and enabling environments for mitigating climate hazards.

Table 2. Intervention characteristics reported in included items

Intervention description	No. of items included in final inventory	Intervention description	No. of items included in final inventory
Climate hazard		Levels of intervention*	
Air pollution	57	Individual and household interventions	30
Extreme heat	18	Community and service interventions	18
Air pollution and extreme heat	1	Structural interventions	14
Population of interest*		Policy interventions	16
Children	65	Evaluated interventions	
Newborns	12	Air pollution	55
Pregnant women/postpartum women	10	Extreme heat	5
Parents of newborns/children	10	Air pollution and extreme heat	1

*Multiple areas of interest mean the total 'n' is larger than the final inventory of items (n=76)

The largest number of included items presented interventions focused on individuals and families (n=30, 39.5%), followed by communities and service interventions (n=18, 23.7%). Sixteen items focused on interventions at the policy-level, while fifteen items focused on interventions that addressed school and/or hospital structures or urban landscaping.

Sixty-one (80.3%) of items included an evaluation. No items identified through grey literature were evaluated, although the interventions might have been evaluated in literature not captured in this review. Of evaluations, 55 (90.2%) were for interventions relating to air pollution, five (8.2%) were for interventions relating to extreme heat, and one (1.6%) was for an intervention relating to both air pollution and extreme heat. Sixteen (26.2%) evaluations were randomised controlled trials (RCTs) or other interventions that used randomisation, of which six were evaluations of different outcomes from the same RCT in Mongolia. A further fifteen (24.6%) evaluations used regression analyses, *t* tests, and ANOVA. The remainder included quasi-experimental evaluation designs, modelling of outputs and comparisons pre-post intervention, and mixed methods. One evaluation used qualitative methods.

The majority of items were focused in one country (n=73, 96.1%) (Table 3). The greatest share of these items was based in the Global North (n=51, 67.1%), with 17 (22.4%) items based in the USA; 32 (42.1%) included items were based in the Global South. Seven items were based in Mongolia, with six of these stemming from the same umbrella intervention but reporting on different outcomes and intervention strands.

Interventions pertaining to individuals and families

The largest proportion of items in the inventory (n=30, 39.5%) described and/or evaluated interventions that were focused on individuals or families. Twenty-seven of these related to air pollution and three of these related to extreme heat.

Air pollution

Interventions with individuals and families used a number of different strategies to encourage behaviours to adapt to the effects of air pollution. The ENRRICH intervention, USA, was a strategic partnership for change with an environmental justice community and included an educational theatrical production and materials for children and families on respiratory health and air pollution [37]. A randomised trial in Cyprus and Greece included warnings for parents on air pollution exposure in homes, to promote adaptation and harm reduction behaviours [38].

Table 3. Geographic distribution of interventions identified according to WHO regions*

Region/country	Studies included in final inventory, n (%)	Region/country	Studies included in final inventory, n (%)
African Region		South-East Asia Region	
South Africa	1 (1.3%)	Bangladesh	1 (1.3%)
Eastern Mediterranean Region		India	7 (9.2%)
Iran	3 (3.9%)	Indonesia	1 (1.3%)
Pakistan	1 (1.3%)	Pakistan	1 (1.3%)
United Arab Emirates	1 (1.3%)	Region of the Americas	
European Region		Brazil	1 (1.3%)
Cyprus	1 (1.3%)	Canada	4 (5.3%)
France	3 (3.9%)	Ecuador	1 (1.3%)
Germany	2 (2.6%)	Peru	1 (1.3%)
Greece	2 (2.6%)	USA	17 (22.4%)
Italy	2 (2.6%)	Western Pacific Region	
Netherlands	1 (1.3%)	Australia	1 (1.3%)
Norway	1 (1.3%)	China	6 (7.9%)
Portugal	3 (3.9%)	Japan	1 (1.3%)
Switzerland	2 (2.6%)	Mongolia	7 (9.2%)
Spain	1 (1.3%)	New Zealand	1 (1.3%)
UK	6 (7.9%)	South Korea	3 (3.9%)
		Global	1 (1.3%)

WHO – World Health Organization

*Multiple geographies of interest mean the total ‘n’ is larger than the final inventory of items (n = 76).

In New Zealand, an intervention that measured exposure to air pollution on two walking routes to school, children and carers/parents were encouraged to change their routes to reduce exposure to traffic-related pollution [39]. In Australia, an intervention sought to reduce car idling outside of schools through signage, newsletters, and fact sheets, measuring air pollutant concentrations as the outcome [40]. In an intervention conducted in fifteen primary schools in the UK, air quality monitors were used to measure exposure to air pollution for children and parents participating in travel to school, providing evidence that could be used to inform behaviour change interventions around how to adapt to air pollution exposure [41].

Two interventions focused on the provision of masks to children; one in the UK used children’s ratings of masks as the outcome of interest [42]. The second, in Indonesia, looked at the effectiveness of wearing surgical masks, bandanas, and motorcycle masks using exposure to pollutants as the outcome of interest [43]. An intervention in households in Peru sought to improve the environmental health of people through hygiene education and a child development programme, with indoor air pollution levels measured as the outcome of interest [44]. In Switzerland, a case study with five infants aged 3–14 months used monitors to measure air quality that generated evidence to inform safer sleeping environments [45].

Fourteen interventions focused on measuring the effect of air purifier use on a variety of outcomes. Six interventions all drew from the Ulaanbaatar Gestation and Air Pollution Research Study, Mongolia [46–51]. The randomised controlled trial recruited non-smoking pregnant women, with intervention groups given 1–2 High Particulate Air Filters (HEPA) for their homes to evaluate their impact on MNCH outcomes. Studies measured birth weight, gestational age-adjusted birth weight, birth length, head circumference, gestational age at birth, and size at gestational age [46], air pollution concentration and blood cadmium levels in later pregnancy [47], parent reported scores of behaviours associated with autism [48], parent reported behaviours of children [49], childhood BMI [50], and cognitive outcomes among children [51].

A further eight interventions focused on the use of air purifiers to mitigate the effects of air pollution in the home. All of these eight interventions were particularly focused on fine particulate matter (PM_{2.5}) and child health, with interventions also including measurement of coarse particulate matter (PM₁₀), ammonia (NH₃), carbon monoxide (CO), and carbon dioxide (CO₂). Five inter-

ventions were based in households in various contexts in the USA [52–56], two were in Shanghai, China [57,58], and one was based in South Korea [59]. Asthma control and management was the outcome measured for four interventions [52–54,59], and air pollutant concentration was the outcome measured for the other four [55–58].

Pregnant women's health was the primary area of focus in only four included items. An educational intervention in Iran aimed to increase awareness among pregnant women of the effects of air pollution and reduce barriers to adapting individual behaviour to reduce exposure, including distribution of masks [60]. The intervention measured awareness of air pollution risks as the primary outcome of interest. In South Korea, an eight-part educational programme with pregnant women comprised of different elements of environmental risks, including air pollution. The intervention measured pregnant women's knowledge and awareness on pollutants, finding that pregnant women in intervention groups had increased knowledge of risks from pollutant exposure than those in the control group [61]. Two separate alert system interventions in Iran used mobile-phone messaging to alert pregnant women to air pollutant exposure and promote adaptation behaviours [62,63]. One of these interventions also included a small-group interview focused on air pollution adaptation behaviours and provision of an educational booklet [62].

Extreme heat

Only three interventions pertaining to individuals or families focused on extreme heat. Two grey literature reports focused on the EXTREMA mobile application. The application informs individuals about heat risks, responding to real-time satellite data that geolocates areas of heat risks. It takes into account information on the individual including socio-demographic characteristics, any existing health conditions, and use of medication. An intervention in Paris partnered with the National Observatory of Athens to launch EXTREMA for city residents to stay cool during extreme events [64], and a multi-country launch was initiated across Greece, Spain, Italy, France, and the Netherlands for the app and additional web service dashboard for municipalities to manage information [65]. An intervention with children in China, based in two schools, aimed to raise awareness towards extreme heat and encourage adaptation practices, with the intervention measuring children's knowledge, awareness, and practice scores [66].

Interventions pertaining to communities, school and health workers

Eighteen inventory items included interventions that engaged with the community as a whole, including people who work in schools, and people who work in health services. These interventions were primarily focused on air pollution (n=11), with fewer on extreme heat (n=7).

Air pollution

Community-based interventions included public awareness campaigns and promoting adaptation strategies for air pollution. In Mongolia, an intervention to adapt to the impact of winter air pollution included a large public awareness campaign, policy advocacy, training for health practitioners, and research and evidence generation [67]. The ENRRICH intervention, USA, included school-based adaptation strategies for air pollution (e.g. air filtration), alongside starting a screening clinic in the school for respiratory illnesses associated with exposure. Impact was measured through tracking awareness raising among the populations of interest and respiratory screening programme outcomes [37]. A study in China evaluated the impact of an intervention to raise awareness among child health providers, community stakeholders, and decision makers around the effects of environmental health, using air pollution and other climate health related knowledge measures as the outcome of interest [68].

Many interventions included components aimed at improving awareness among teachers and school-based staff of climate risks. An intervention in Italy alerted teachers of higher air pollution via WhatsApp, after which they were instructed to keep windows closed and use air purifi-

ers to mitigate air pollutant exposure in children's classrooms [69]. An intervention in Norway installed seventeen low-cost air quality nodes in kindergartens to monitor air quality and children's exposures to CO, NO, NO₂, and O₃, in order for kindergarten staff to plan activities according to exposure risk [70]. In Cyprus and Greece, a randomised trial involved desert dust storm warnings for parents and teachers to reduce pollution exposure among asthmatic children, including guidelines for reducing exposure to PM_{2.5} and PM₁₀ in homes and schools alongside installing air cleaners [38].

Further interventions were aimed at changing knowledge and behaviours in schools that could help children adapt to air pollution. An intervention in the USA assessed 36 childcare centres that were randomised into a stepped-wedge protocol of a 'Greener Cleaning' educational programme taught by nursing students, community health workers, or asthma coalition members [71]. The intervention had no effect on cleaning behaviours to reduce PM_{2.5} and CO₂ pollutants. A study in Ottawa, Canada, explored the impact of changing the timings of air ventilation use in schools to account for rush hour traffic, measuring air pollution concentrations and finding a significant reduction for schools that start at 9am, but no reduction for schools that start at 8am [72].

In Portugal, a study in nursery and primary schools evaluated an intervention that focused on various components to improve indoor air quality: awareness, behaviours, activities, technologies, and structures [73]. The intervention saw mitigating effects primarily on CO₂ levels but no decrease in broader pollutant concentrations to safe levels. Another intervention in Portugal focused on improving school staff knowledge of how to improve indoor air quality through instructions and dedicated guidelines. The intervention included a measure of atopic disease to assess the intervention quality, though the schools saw no reduction in pollutants (PM_{2.5} and PM₁₀) [74]. An intervention based in the UK involved training materials co-designed with children, parents of children with asthma, community members, and health professionals on asthma counselling and care that were disseminated among health workers through virtual training sessions and general practitioner surgery engagement settings [75]. This included discussions on asthma and air pollution.

Extreme heat

Community-based interventions included education and awareness raising about extreme heat. In France, a national heat-wave plan included educational materials shared among key stakeholders including health workers and the broader populations to help understand the health effects of heat and associated risks [65]. In Maricopa, USA, workshops were conducted to educate the community on heat action plans and urban heat island hotspots, including parks for children [76]. A heat wave forecast intervention in Vietnam aimed to implement early actions to reduce heat-related health impacts such as shelters, cooling centres, and fans with ice tanks [77].

School workers in the USA that participated in the 'HeatReady' intervention were trained to identify and adapt to the impacts of school-based extreme heat, measured by knowledge and awareness of heat preparedness [78]. The 'HeatReady' intervention aims to build capacity for schools to adapt to the negative impacts of schoolground heat with the aim of improving children's health and demonstrating that heat safety resources and readiness plans remained under-utilised within schools.

A Heat Action Plan, developed in response to a 2010 heat wave in Ahmedabad, India, included multiple components in its public awareness campaigns and health provider education around the effects of extreme heat and how to adapt to these [76,79]. These also included structural changes to buildings and awareness raising and outreach in schools and with parents and children. A study on the effects of extreme heat evaluated the implementation of heat wave alerts in South Korea, which triggered working hour changes, opening of shade shelters, and deployment of health workers to support climate hazard adaptation [80].

Interventions based around school and hospital structures and urban landscaping

Fourteen interventions included items focused on the adaptation of school or hospital structures or the urban landscape to reduce the effects of air pollution (n=4), extreme heat (n=9), and both (n=1). All interventions focused on child health as the primary MNCH outcome of interest. One study in the USA analysed the structural renovation of schools, including a new heating, ventilation, and air conditioning system to mitigate both extreme heat and air pollution [76].

Air pollution

Included items examined the role of green space-related interventions on children's health and interventions involving modifications to park and public spaces frequently used by children. Two of these were related to nature-based interventions; planting roadside vegetation in areas frequented by children in the UK [77] and planting green features (trees, wildflower meadows, etc) in elementary school playgrounds in the USA [78]. A further study looked at the effect of the implementation of green and blue spaces in Portugal on children's health [79].

Items explored the impact of modifying specifically school structures, layouts, and ventilation systems on adapting to the effects of air pollution and extreme heat. In the United Arab Emirates, an intervention that implemented air purifiers, interior renovations with low-emission finishing materials, and new ventilation systems was evaluated based on the presence of air pollution indoors with the aim of improving children's health [80].

Extreme heat

A complex intervention in Paris included mapping and developing 'cool islands' – swimming area, water/misting feature, or air-conditioned buildings – to ensure that residents lived within a seven-minute walk of one by 2020. Shading and greenery were developed in schoolyards for cooling under an 'Urban Oasis' scheme, and 'Cool Pathways' linked the cool islands to minimise discomfort when travelling, including creating tree canopies, solar reflective pavements, or other shading structures [64]. In Cape Town, South Africa, spray parks were installed in recreational spaces in lower income areas to provide cooling services particularly for children [81]. These require less water than swimming pools, which meant they were more feasible for water-stressed cities such as Cape Town.

Three separate interventions in three Canadian cities sought to reduce the effects of extreme heat through infrastructural changes and greening efforts. Interventions included to 'green' Anna Street in Québec, an area chosen specifically due to its location near schools to benefit children [82]. The intervention included planting trees, creating rain gardens, and installing permeable surfaces. Shade in areas predominantly used by children was the key intervention focus in Toronto, and in Ontario shade structures, water fountains, and trees were planted to improve shade in parks and playgrounds [82].

Further inventory items included interventions that related to the modification of a broader variety of buildings, including schools and hospitals. In particular, interventions in Ahmedabad [83,84] and Delhi [85], in India, identified in the grey literature focused on 'cool roofs' as cost-effective mechanisms to reduce the effects of extreme heat in urban areas. An intervention in Vietnam to mitigate extreme heat included the establishment of cooling centres, as well as household retrofitting and provision of cooling fans with ice tanks for night-time use [81]. Cooling systems such as thermal energy storage tanks and environmentally-friendly refrigerants were also embedded in a high-density city development project in Gujarat, India, including in schools [83].

Policy-based interventions

Sixteen studies included a policy-based intervention, with seven focused on transportation and traffic-related policies. The majority (n=15) of these studies were relating to policies to either adapt or mitigate air pollution, with only one related to adaptation to extreme heat.

Air pollution

A large proportion (n=7) of the inventory items assessing policies were focused on transportation and traffic policies. These policies focused on transportation and traffic and were situated in a range of contexts – Brazil [86], Ecuador [87], Germany [88], Japan [89], the UK [90,91], and the USA [92] – the majority of which (n=5) were based in the Global North. Interventions measured a range of outcomes: respiratory health, premature deaths, adverse birth outcomes, hypertensive disorders, low birth weight, lung function, and air pollution concentrations.

A policy for mandatory motor vehicle inspections (I/M-SP Program) for controlling emissions in São Paulo, Brazil, implemented in 2010 and suspended in 2014, was assessed to see the impact on children's respiratory health, including asthma [86]. There were no effects of the policy on children's health. An assessment of vehicular emission controls in Quito, Ecuador, measured the success of the measures through incidences of acute respiratory illness among children, finding the institutionalisation of the policy correlated with a decline in acute respiratory infection between 2000 and 2007 [87]. The Automobile NO_x law (1992) that regulated vehicles in Japan through inspections was estimated to reduce air pollution as well as foetal death rates, though no associations were found with the infant mortality rate, low birth weights, or neonatal mortality rate [89]. A further item evaluated a battery of Environmental Protection Agency programmes in the USA, between 1996 and 2008, which aimed to reduce traffic-related air pollution. It measured the impact on newborn health through term birth weight, finding that policies were linked to a decrease in outdoor NO₂ concentrations and an increase in birth weights [92].

Three studies examined low-emission zones (LEZ) in urban areas (banning air-polluting vehicles from city centres). In Germany, a natural experiment of staggered introduction of LEZs had a small impact on low-birth-weight rates [88]. Two interventions explored the impact of LEZ in London, UK. The LEZ policy was not found to have had an impact when measuring intervention effectiveness through improved lung function among children [90]. However, in a separate study, the LEZ policy was found to reduce the concentrations of harmful air pollutants, particularly NO₂ [91].

A number of items focused on the adoption of air quality targets and standards to reduce air pollution. An evaluation of global clean air policies focused on the effect on children's exposure to PM_{2.5} and NO₂ using premature mortality of children under five as the measure of effectiveness [93]. It estimated the impact of implementing existing regional air quality standards across the globe, finding that implementation of PM_{2.5} limits would significantly reduce premature mortality. Another study assessed current mortality associated with air pollution among infants living in thirteen 'megacities' in Bangladesh, China, India, and Pakistan and estimated the impact of mitigation strategies [94]. It found that policies to reduce PM_{2.5} could reduce incidences of acute lower respiratory infection and premature mortality of children in all cities. An analysis of the impact of a supra-municipal plan of measures to reduce air pollution in different sectors such as transport, energy, and industry in Agglomeration of Lausanne-Morges, Switzerland, between 2005 and 2015 that included measures to reduce air pollution estimated that the plan prevented 26 premature deaths among infants and reduced bronchitis and asthma cases [95].

Four items in the USA examined the impact of policies on emissions that went beyond traffic-related pollutants. These included regulating emissions from powerplants [96,97] and electric power stations [98] and the implementation of federal environmental health protections [99]. One study explored the impact of the Clean Air Interstate Rule on newborn and child health, measured by

improvements in premature births, infant mortality, gestational length, and birth weight [97]. To evaluate the impact of the US Regional Greenhouse Gas Initiative on newborn and child health, one study measured asthma incidence and term low birth rate, finding the former had the highest change in incidence and the latter the lowest [98]. A further study assessed the impact of the closure of a powerplant in Pennsylvania on newborn health in New Jersey, finding that it was associated with a decrease in low birth weights [96]. A final study provided recommendations based on an intervention entitled Project TENDR, which aimed to examine the links between exposure to toxic chemicals including PM_{2.5} and brain development [99].

Extreme heat

One included item evaluated two interventions in India that aimed to assist communities and individuals to adapt to extreme heat: the National Rural Employment Guarantee Act that supported rural workers impacted by temperature fluctuations and the Accredited Social Health Activists that aimed to expand formal health services [100]. These interventions sought to generate behaviour change through policy implementation. The intervention evaluation found that only the health programme was effective in modifying the relationship between extreme temperatures and infant mortality in rural India [100].

DISCUSSION

Given the increasing awareness of the impact of climate change on MNCH, we conducted this mapping to identify existing literature on interventions that have been implemented to reduce the impact of air pollution and/or extreme heat on MNCH, to contribute to an understanding of the available evidence base and to provide information to countries so that they can start discussing promising interventions and potential solutions [1,3,17,23].

The published literature identified was dominated by the interventions on ambient air pollution (75%); with interventions particularly focused around individuals and families. The few interventions that addressed extreme heat were identified in grey literature, were implemented predominantly in the Global North and related to structural modifications to the urban and environmental landscape and heat health plans. Only one item addressed both extreme heat and air pollution. The causes of air pollution and extreme heat are interrelated, and the multiplicative effects of these two climate hazards on population health, and the potential benefits of combined mitigation efforts, make integrated interventions important [101].

Within MNCH, existing interventions primarily focus on child health as the issue driving the intervention or the outcome of interest. This included interventions aimed at improving air quality in the home as well as air quality relating to school environments and journeys to/from school. Some interventions might have secondary impacts on the health of mothers, pregnant women, parents, carers, or newborns, but these were not made explicit. There was a dearth of interventions that specifically targeted pregnant women and post-partum or lactating women. Interventions designed to mitigate the effects of air pollution or extreme heat on pregnant women typically looked at birth outcomes (gestational length, birth weight, live births).

It is notable that overall fewer interventions were focused in the Global South, given that the effects of extreme heat and ambient air pollution are likely to have an uneven distribution with Global South contexts more significantly impacted by the effects of extreme heat and ambient air pollution [9,10]. Mapping the geographic spread uncovers a hegemony of interventions being conducted in the Global North, particularly the USA. The impacts of climate change are predicted to be more acute in Global South contexts [3,102], and people are made more vulnerable due to less health infrastructure, inequalities in access and health system funding and provision. Thus, it is particularly important to understand contextually effective interventions to mitigate and adapt to the effects of air pollution and extreme heat particularly in the Global South.

The largest proportion of interventions pertained to individuals and families, particularly focusing on household-based changes such as installation of air purifiers. These interventions can have an effect on reducing exposure to air pollution in the home, but are unlikely to change exposures elsewhere. This may also not consider the socio-economic, cultural, and political factors that are important determinants of the health impact. Moreover, scalability may be complicated by the availability and accessibility of technologies that might be particularly unfeasible for people of lower income strata. A similar proportion of interventions were based at the community-level or with school/health workers, were relating to adaptations to school or hospital structures/the urban landscape, or were policy based. For only interventions relating to structural changes extreme heat was the more common focus than air pollution; there was a paucity of policy-based interventions that aimed to reduce the effects of extreme heat. Health systems remained largely overlooked across interventions, despite the critical role that these play in managing the effects of the climate crisis [103].

This mapping – through a scoping review of the literature – highlights the current dearth of research that accounts for potential resource and infrastructural barriers to mitigation and adaptation strategies. These barriers may be unequal across contexts and limit the potential applicability of different strategies in different contexts. This includes engaging with indigenous models of protection and health care, which are shown to improve quality of care delivery for MNCH when provided alongside biomedical care [104]. This includes the linking of approaches to adapting to climate crisis hazards [105].

A scoping review does not assess the quality or effectiveness of interventions [106]. As the body of literature grows, conducting systematic reviews of effectiveness will become important. Various languages were screened in the search (English, French, German, Japanese, Mandarin, Spanish,), however, items identified but published in Polish and Korean were excluded despite being potentially relevant to the review. This was due to the language limitations of the research team. Moreover, English search terms will likely have biased the search towards English-language studies that might lead to a greater focus on English-speaking contexts. Finally, the scoping review was limited by the predominantly biomedical databases used. Future reviews can develop on this body of work by broadening the search strategy to include further databases and grey literature, alongside including more languages. Despite these limitations, the inventory presented in this scoping review is a necessary starting point and future work can build on the gaps identified. Moreover, we recommend that this inventory be updated periodically to reflect increasing policies and interventions in this field. This includes an upcoming World Health Organization content analysis of national heat health plans.

CONCLUSIONS

This inventory highlights key gaps, as well as an understanding of what interventions have already been done. This is of key critical importance as countries increasingly seek action plans to mitigate and adapt to climate hazards. By mapping interventions, this scoping review is an important step in building the evidence base for future work. The review highlights a number of important considerations for researchers and policymakers. There was a paucity of interventions with health workers, who can have a key role in supporting adaptation efforts towards the effects of climate change, alongside providing care for populations impacted by climate change. There was a notable dearth of journal-based literature on interventions in Global South contexts that are most vulnerable to the effects of the climate crisis. Future research and interventions should focus on the reduction of climate crisis effects in these contexts. Interventions that incorporated or were grounded on contextual and/or indigenous mechanisms for reducing the impact of climate change were sparse and might be especially relevant for ensuring cultural and contextual specificity. More multi-sectoral interventions are needed as well as individual / family-based interventions for heat. Further interventions aimed at strengthening the health system, increas-

ing health worker awareness of climate hazard related care, and overcoming the challenges for these interventions are needed. Much of the literature focused on children, with fewer interventions considering pregnant and postpartum women's health and well-being. These are critical areas of MNCH and more research would be beneficial. Interventions primarily focused on air pollution concentrations as a key exposure of interest. Further research should interrogate the possible impact of interventions in reducing the effects of air pollution and extreme heat on a broader spectrum of health outcomes within MNCH.

A growing body of work highlights the impacts of climate change on MNCH. Decision makers and programme managers will be interested in implementing interventions to reduce these impacts. This review highlights potential interventions although evaluations are lacking. We highlight the importance of taking stock of what has been done and starting dialogue to discuss the way forward and how to build an evidence base. Discussion can focus on how interventions can be adapted, monitored and evaluated, with lessons learned being documented and shared.

Acknowledgements: We are grateful for the work of Diana Manianchira and Kalyani Mohan in supporting the screening of these articles and reviewing the literature, as well as Prof Ernestina Coast (London School of Economics) for her supervision and mentorship of the original scoping review design and implementation.

Disclaimer: The authors alone are responsible for the views expressed in this article and they do not necessarily represent the views, decisions or policies of the institutions with which they are affiliated.

Funding: The study was not funded.

Authorship contributions: AP conceived the review, RB, ZS, and MOH conducted the review with AP, FC, and JS. All authors conducted the analysis with JS leading. JS wrote a first draft of the manuscript. All authors participated in the development and finalisation of the manuscript.

Disclosure of interest: The authors completed the ICMJE Disclosure of Interest Form (available upon request from the corresponding author) and disclose no relevant interests.

Additional material

Online Supplementary Document

REFERENCES

- 1 World Health Organization. Protecting maternal, newborn and child health from the impacts of climate change: call for action. Geneva: World Health Organization; 2023.
- 2 Patel L, Friedman E, Johannes SA, Lee SS, O'Brien HG, Schear SE. Air pollution as a social and structural determinant of health. *J Clim Change Health*. 2021;3:100035. doi:10.1016/j.jocl.2021.100035
- 3 Arpin E, Gauffin K, Kerr M, Hjern A, Mashford-Pringle A, Barros A, et al. Climate Change and Child Health Inequality: A Review of Reviews. *Int J Environ Res Public Health*. 2021;18:10896. Medline:34682662 doi:10.3390/ijerph182010896
- 4 Rylander C, Odland J, Sandanger TM. Climate change and the potential effects on maternal and pregnancy outcomes: an assessment of the most vulnerable—the mother, fetus, and newborn child. *Glob Health Action*. 2013;6:19538. Medline:23481091 doi:10.3402/gha.v6i0.19538
- 5 Levy BS, Patz JA. Climate Change, Human Rights, and Social Justice. *Ann Glob Health*. 2015;81:310–22. Medline:26615065 doi:10.1016/j.aogh.2015.08.008
- 6 IPCC. In: Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JBR, Maycock TK, Waterfield T, Yelekçi O, Yu R, Zhou B, editors. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press; 2021. Available: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport.pdf. Accessed: 6 February 2025.
- 7 Kinney PL, Pinkerton KE. Heatwaves and Air Pollution: a Deadly Combination. *Am J Respir Crit Care Med*. 2022;206:1060–2. Medline:35877995 doi:10.1164/rccm.202207-1372ED
- 8 Schnell JL, Prather MJ. Co-occurrence of extremes in surface ozone, particulate matter, and temperature over eastern North America. *Proc Natl Acad Sci U S A*. 2017;114:2854–9. Medline:28242682 doi:10.1073/pnas.1614453114

- 9 Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet*. 2009;373:1693–733. [Medline:19447250](#) [doi:10.1016/S0140-6736\(09\)60935-1](#)
- 10 Intergovernmental Panel On Climate Change. *Climate change 2007: The physical science basis*. Cambridge, UK and New York, NY, USA: Cambridge University Press;2007.
- 11 Perera F, Nadeau K. Climate Change, Fossil-Fuel Pollution, and Children's Health. *N Engl J Med*. 2022;386:2303–14. [Medline:35704482](#) [doi:10.1056/NEJMra2117706](#)
- 12 Johnson NM, Hoffmann AR, Behlen JC, Lau C, Pendleton D, Harvey N, et al. Air pollution and children's health—a review of adverse effects associated with prenatal exposure from fine to ultrafine particulate matter. *Environ Health Prev Med*. 2021;26:72. [Medline:34253165](#) [doi:10.1186/s12199-021-00995-5](#)
- 13 Al Nahian M, Ahmad T, Jahan I, Chakraborty N, Nahar Q, Streatfield PK. Air pollution and pregnancy outcomes in Dhaka, Bangladesh. *J Clim Change Health*. 2023;9:100187. [doi:10.1016/j.joclim.2022.100187](#)
- 14 Ghosh R, Causey K, Burkart K, Wozniak S, Cohen A, Brauer M. Ambient and household PM2.5 pollution and adverse perinatal outcomes: A meta-regression and analysis of attributable global burden for 204 countries and territories. *PLoS Med*. 2021;18:e1003718. [Medline:34582444](#) [doi:10.1371/journal.pmed.1003718](#)
- 15 Yang J, Chen X, Yamamoto Y. The final 28 Days: Prenatal exposure to air pollution and child anthropometric outcomes. *J Environ Manage*. 2023;342:118289. [Medline:37279606](#) [doi:10.1016/j.jenvman.2023.118289](#)
- 16 Odo DB, Yang IA, Dey S, Hammer MS, van Donkelaar A, Martin RV, et al. A cross-sectional analysis of long-term exposure to ambient air pollution and cognitive development in children aged 3–4 years living in 12 low- and middle-income countries. *Environ Pollut*. 2023;318:120916. [Medline:36563987](#) [doi:10.1016/j.envpol.2022.120916](#)
- 17 Syed S, O'Sullivan TL, Phillips KP. Extreme Heat and Pregnancy Outcomes: A Scoping Review of the Epidemiological Evidence. *Int J Environ Res Public Health*. 2022;19:2412. [Medline:35206601](#) [doi:10.3390/ijerph19042412](#)
- 18 Ilango SD, Weaver M, Sheridan P, Schwarz L, Clemesha RES, Bruckner T, et al. Extreme heat episodes and risk of preterm birth in California, 2005–2013. *Environ Int*. 2020;137:105541. [Medline:32059147](#) [doi:10.1016/j.envint.2020.105541](#)
- 19 McElroy S, Ilango S, Dimitrova A, Gershunov A, Benmarhnia T. Extreme heat, preterm birth, and stillbirth: A global analysis across 14 lower-middle income countries. *Environ Int*. 2022;158:106902. [Medline:34627013](#) [doi:10.1016/j.envint.2021.106902](#)
- 20 DeFranco E, Hall E, Hossain M, Chen A, Haynes EN, Jones D, et al. Air Pollution and Stillbirth Risk: Exposure to Airborne Particulate Matter during Pregnancy Is Associated with Fetal Death. *PLoS One*. 2015;10:e0120594. [Medline:25794052](#) [doi:10.1371/journal.pone.0120594](#)
- 21 Grace K, Davenport F, Hanson H, Funk C, Shukla S. Linking climate change and health outcomes: Examining the relationship between temperature, precipitation and birth weight in Africa. *Glob Environ Change*. 2015;35:125–37. [doi:10.1016/j.gloenvcha.2015.06.010](#)
- 22 Blom S, Ortiz-Bobeo A, Hoddinott J. Heat exposure and child nutrition: Evidence from West Africa. *J Environ Econ Manage*. 2022;115:102698. [doi:10.1016/j.jeem.2022.102698](#)
- 23 Lakhoo DP, Blake HA, Chersich MF, Nakstad B, Kovats S. The Effect of High and Low Ambient Temperature on Infant Health: A Systematic Review. *Int J Environ Res Public Health*. 2022;19:9109. [Medline:35897477](#) [doi:10.3390/ijerph19159109](#)
- 24 Prina M, Khan N, Akhter Khan S, Caicedo JC, Peycheva A, Seo V, et al. Climate change and healthy ageing: An assessment of the impact of climate hazards on older people. *J Glob Health*. 2024;14:04101. [Medline:38783708](#) [doi:10.7189/jogh.14.04101](#)
- 25 Proulx K, Daelmans B, Baltag V, Banati P. Climate change impacts on child and adolescent health and well-being: A narrative review. *J Glob Health*. 2024;14:04061. [Medline:38781568](#) [doi:10.7189/jogh.14.04061](#)
- 26 Etzel RA, Weimann E, Homer C, Arora NK, Maimela G, Prats EV, et al. Climate change impacts on health across the life course. *J Glob Health*. 2024;14:03018. [Medline:38781571](#) [doi:10.7189/jogh.14.03018](#)
- 27 Chersich MF, Pham MD, Areal A, Haghghi MM, Manyuchi A, Swift CP, et al. Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis. *BMJ*. 2020;371:m3811. [Medline:33148618](#) [doi:10.1136/bmj.m3811](#)
- 28 Li C, Yang M, Zhu Z, Sun S, Zhang Q, Cao J, et al. Maternal exposure to air pollution and the risk of low birth weight: A meta-analysis of cohort studies. *Environ Res*. 2020;190:109970. [Medline:32763280](#) [doi:10.1016/j.envres.2020.109970](#)
- 29 Theron E, Bills CB, Calvillo Hynes EJ, Stassen W, Rublee C. Climate change and emergency care in Africa: A scoping review. *Afr J Emerg Med*. 2022;12:121–8. [Medline:35371912](#) [doi:10.1016/j.afjem.2022.02.003](#)

- 30 Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol*. 2005;8:19–32. doi:10.1080/1364557032000119616
- 31 Peters MDJ, Godfrey C, McInerney P, Munn Z, Tricco AC, Khalil H. Scoping Reviews (2020). In: Aromataris E, Munn Z, editors. *JBIManual for Evidence Synthesis*. 2024. pp. 417-476. Available: <https://synthesismanual.jbi.global>. Accessed: 6 February 2025.
- 32 Strong J, Barrett R, Manianchira D, O'Hare M, Surtee Z, Conway F, et al. The impact of extreme heat and air pollution on maternal, newborn, and child health outcomes: A scoping review [Protocol]. 2023. Available: https://figshare.com/articles/journal_contribution/The_impact_of_extreme_heat_and_air_pollution_on_maternal_newborn_and_child_health_outcomes_A_scoping_review/24220690/1?file=42509755. Accessed: 5 August 2024.
- 33 Benova L, Huysmans E, Portela A. Rapid scoping review of measures taken to maintain the provision and the use of essential services for MNCAAH (maternal, newborn, child, adolescent and older person's health). 2021. Available: <https://www.protocols.io/view/rapid-scoping-review-of-measures-taken-to-maintain-dm6gpr4kd-vzp/v2>. Accessed: 31 July 2024.
- 34 Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Ann Intern Med*. 2018;169:467–73. Medline:30178033 doi:10.7326/M18-0850
- 35 Ma PHX, Chan ZCY, Loke AY. The Socio-Ecological Model Approach to Understanding Barriers and Facilitators to the Accessing of Health Services by Sex Workers: A Systematic Review. *AIDS Behav*. 2017;21:2412–38. Medline:28631228 doi:10.1007/s10461-017-1818-2
- 36 Strong J, Coast E, Nandagiri R. Abortion, Stigma, and Intersectionality. In: Liamputtong P, editor. *Handbook of Social Sciences and Global Public Health*. Cham: Springer International Publishing; 2023. p. 1-22.
- 37 Spencer-Hwang R, Soret S, Valladares J, Torres X, Pasco-Rubio M, Dougherty M, et al. Strategic Partnerships for Change in an Environmental Justice Community: The ENRRICH Study. *Prog Community Health Partnersh*. 2016;10:541–50. Medline:28569679 doi:10.1353/cpr.2016.0062
- 38 Kouis P, Michailidi E, Papatheodorou SI, Kakkoura MG, Dimitriou E, Koutrakis P, et al. Mitigating the health effects of Desert Dust Storms through exposure reduction approaches: The LIFE MEDEA Asthma study. *Eur Respir J*. 2019;54:PA2831. doi:10.1183/13993003.congress-2019.PA2831
- 39 Dirks KN, Salmond JA, Talbot N. Air Pollution Exposure in Walking School Bus Routes: A New Zealand Case Study. *Int J Environ Res Public Health*. 2018;15:2802. Medline:30544674 doi:10.3390/ijerph15122802
- 40 Rumchev K, Lee A, Maycock B, Jancey J. Reducing car idling at primary schools: An intervention study of parent behaviour change in Perth, Western Australia. *Health Promot J Austr*. 2021;32:383–90. Medline:32594615 doi:10.1002/hpja.381
- 41 Heydon J, Chakraborty R. Can portable air quality monitors protect children from air pollution on the school run? An exploratory study. *Environ Monit Assess*. 2020;192:195. Medline:32086616 doi:10.1007/s10661-020-8153-1
- 42 Smart NR, Horwell CJ, Smart TS, Galea KS. Assessment of the Wearability of Facemasks against Air Pollution in Primary School-Aged Children in London. *Int J Environ Res Public Health*. 2020;17:3935. Medline:32498327 doi:10.3390/ijerph17113935
- 43 Patel D, Shibata T, Wilson J, Maidin A. Challenges in evaluating PM concentration levels, commuting exposure, and mask efficacy in reducing PM exposure in growing, urban communities in a developing country. *Sci Total Environ*. 2016;543:416–24. Medline:26599141 doi:10.1016/j.scitotenv.2015.10.163
- 44 Hartinger SM, Nuño N, Hattendorf J, Verastegui H, Karlen W, Ortiz M, et al. A factorial cluster-randomised controlled trial combining home-environmental and early child development interventions to improve child health and development: rationale, trial design and baseline findings. *BMC Med Res Methodol*. 2020;20:73. Medline:32241260 doi:10.1186/s12874-020-00950-y
- 45 De La Iglesia DH, De Paz JF, Villarrubia González G, Barriuso AL, Bajo J. A Context-Aware Indoor Air Quality System for Sudden Infant Death Syndrome Prevention. *Sensors (Basel)*. 2018;18:757. Medline:29498653 doi:10.3390/s18030757
- 46 Barn P, Gombojav E, Ochir C, Boldbaatar B, Beejin B, Naidan G, et al. The effect of portable HEPA filter air cleaner use during pregnancy on fetal growth: The UGAAR randomized controlled trial. *Environ Int*. 2018;121:981–9. Medline:30213473 doi:10.1016/j.envint.2018.08.036
- 47 Barn P, Gombojav E, Ochir C, Laagan B, Beejin B, Naidan G, et al. The effect of portable HEPA filter air cleaners on indoor PM(2.5) concentrations and second hand tobacco smoke exposure among pregnant women in Ulaanbaatar, Mongolia: The UGAAR randomized controlled trial. *Sci Total Environ*. 2018;615:1379–89. Medline:29751442 doi:10.1016/j.scitotenv.2017.09.291
- 48 Enkhbat U, Gombojav E, Banzrai C, Batsukh S, Boldbaatar B, Enkhtuya E, et al. Portable HEPA filter air cleaner use during pregnancy and children's autistic behaviors at four years of age: The UGAAR randomized controlled trial. *Environ Int*. 2022;168:107432. Medline:36007302 doi:10.1016/j.envint.2022.107432

- 49 Enkhbat U, Gombojav E, Banzrai C, Batsukh S, Boldbaatar B, Enkhtuya E, et al. Portable HEPA filter air cleaner use during pregnancy and children's behavior problem scores: a secondary analysis of the UGAAR randomized controlled trial. *Environ Health*. 2021;20:78. **Medline:34225757 doi:10.1186/s12940-021-00763-6**
- 50 Tamana SK, Gombojav E, Kanlic A, Banzrai C, Batsukh S, Enkhtuya E, et al. Portable HEPA filter air cleaner use during pregnancy and children's body mass index at two years of age: The UGAAR randomized controlled trial. *Environ Int*. 2021;156:106728. **Medline:34218184 doi:10.1016/j.envint.2021.106728**
- 51 Ulziikhuu B, Gombojav E, Banzrai C, Batsukh S, Enkhtuya E, Boldbaatar B, et al. Portable HEPA Filter Air Cleaner Use during Pregnancy and Children's Cognitive Performance at Four Years of Age: The UGAAR Randomized Controlled Trial. *Environ Health Perspect*. 2022;130:67006. **Medline:35730943 doi:10.1289/EHP10302**
- 52 Kaviany P, Brigham EP, Collaco JM, Rice JL, Woo H, Wood M, et al. Patterns and predictors of air purifier adherence in children with asthma living in low-income, urban households. *J Asthma*. 2022;59:946–55. **Medline:33625291 doi:10.1080/02770903.2021.1893745**
- 53 Moreno-Rangel A, Baek J, Roh T, Xu X, Carrillo G. Assessing Impact of Household Intervention on Indoor Air Quality and Health of Children with Asthma in the US-Mexico Border: A Pilot Study. *J Environ Public Health*. 2020;2020:6042146. **Medline:32831855 doi:10.1155/2020/6042146**
- 54 Park HK, Cheng KC, Tetteh AO, Hildemann LM, Nadeau KC. Effectiveness of air purifier on health outcomes and indoor particles in homes of children with allergic diseases in Fresno, California: A pilot study. *J Asthma*. 2017;54:341–6. **Medline:27723364 doi:10.1080/02770903.2016.1218011**
- 55 Riederer AM, Krenz JE, Tchong-French MI, Torres E, Perez A, Younglove LR, et al. Effectiveness of portable HEPA air cleaners on reducing indoor PM(2.5) and NH(3) in an agricultural cohort of children with asthma: A randomized intervention trial. *Indoor Air*. 2021;31:454–66. **Medline:32996146 doi:10.1111/ina.12753**
- 56 Riederer AM, Krenz JE, Tchong-French MI, Torres E, Perez A, Younglove LR, et al. Effectiveness of portable HEPA air cleaners on reducing indoor endotoxin, PM(10,) and coarse particulate matter in an agricultural cohort of children with asthma: A randomized intervention trial. *Indoor Air*. 2021;31:1926–39. **Medline:34288127 doi:10.1111/ina.12858**
- 57 Barkjohn KK, Norris C, Cui X, Fang L, Zheng T, Schauer JJ, et al. Real-time measurements of PM(2.5) and ozone to assess the effectiveness of residential indoor air filtration in Shanghai homes. *Indoor Air*. 2021;31:74–87. **Medline:32649780 doi:10.1111/ina.12716**
- 58 Brehmer C, Norris C, Barkjohn KK, Bergin MH, Zhang J, Cui X, et al. The impact of household air cleaners on the chemical composition and children's exposure to PM(2.5) metal sources in suburban Shanghai. *Environ Pollut*. 2019;253:190–8. **Medline:31310869 doi:10.1016/j.envpol.2019.07.003**
- 59 Lee GH, Kim JH, Kim S, Lee S, Lim DH. Effects of Indoor Air Purifiers on Children with Asthma. *Yonsei Med J*. 2020;61:310–6. **Medline:32233173 doi:10.3349/ymj.2020.61.4.310**
- 60 Pormosayebi S, Shamsi M, Khorsandi M, Koolivand A, Ranjbaran M. The effect of training based on health belief model (HBM) in preventing exposure to polluted air in pregnant women. *Journal of Babol University of Medical Sciences*. 2018;20:57–63.
- 61 Kim HK, Jeong GH. Effect of Pro-Environmental Prenatal Education Program on Pregnant Women's Environmental Health Awareness and Behaviors based on the Protection Motivation Theory. *Inquiry*. 2022;59:469580211047045. **Medline:35227127 doi:10.1177/00469580211047045**
- 62 Araban M, Tavafian SS, Zarandi SM, Hidarnia AR, Burri A, Montazeri A. A behavioral strategy to minimize air pollution exposure in pregnant women: a randomized controlled trial. *Environ Health Prev Med*. 2017;22:26. **Medline:29165105 doi:10.1186/s12199-017-0633-8**
- 63 Jasezadeh M, Khafaie MA, Jaafarzadeh N, Araban M. Effectiveness of a theory-based mobile phone text message intervention for improving protective behaviors of pregnant women against air pollution: a randomized controlled trial. *Environ Sci Pollut Res Int*. 2018;25:6648–55. **Medline:29260471 doi:10.1007/s11356-017-1034-7**
- 64 ESMAP. Primer for Cool Cities: Reducing Excessive Urban Heat. Energy Sector Management Assistance Program (ESMAP) Knowledge Series 031/20. Washington, DC: World Bank; 2020. Available: <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/605601595393390081/primer-for-cool-cities-reducing-excessive-urban-heat-with-a-focus-on-passive-measures>. Accessed: 5 August 2024.
- 65 World Health Organization. Heat and health in the WHO European Region: updated evidence for effective prevention. Copenhagen: WHO Regional Office for Europe; 2021. Available: <https://iris.who.int/bitstream/handle/10665/339462/9789289055406-eng.pdf>. Accessed: 5 August 2024.
- 66 Li Y, Sun B, Yang C, Zhuang X, Huang L, Wang Q, et al. Effectiveness Evaluation of a Primary School-Based Intervention against Heatwaves in China. *Int J Environ Res Public Health*. 2022;19:2532. **Medline:35270225 doi:10.3390/ijerph19052532**

- 67 UNICEF. Healthy Environments for Healthy Children: Global Programme Framework. New York, NY, USA: UNICEF, 2021. Available: <https://www.unicef.org/media/91216/file/Healthy-Environments-for-Healthy-Children-Global-Programme-Framework-2021.pdf>. Accessed: 5 August 2024.
- 68 Niu J, Qu Q, Li J, Liu X, Zhang B, Li Z, et al. Improving Knowledge about Children's Environmental Health in Northwest China. *Int J Environ Res Public Health*. 2015;13:80. **Medline:26712775 doi:10.3390/ijerph13010080**
- 69 Zauli-Sajani S, Marchesi S, Boselli G, Broglia E, Angella A, Maestri E, et al. Effectiveness of a Protocol to Reduce Children's Exposure to Particulate Matter and NO(2) in Schools during Alert Days. *Int J Environ Res Public Health*. 2022;19:11019. **Medline:36078735 doi:10.3390/ijerph191711019**
- 70 Castell N, Schneider P, Grossberndt S, Fredriksen MF, Sousa-Santos G, Vogt M, et al. Localized real-time information on outdoor air quality at kindergartens in Oslo, Norway using low-cost sensor nodes. *Environ Res*. 2018;165:410–9. **Medline:29106951 doi:10.1016/j.envres.2017.10.019**
- 71 Lee E, Dressel A, Bell-Calvin J, Garacci Z, Steinberg J. Assessment of Indoor Air Quality and Cleaning Behaviors in Urban Child Care Facilities. *J Allergy Clin Immunol*. 2020;145:AB83. **doi:10.1016/j.jaci.2019.12.684**
- 72 MacNeill M, Dobbin N, St-Jean M, Wallace L, Marro L, Shin T, et al. Can changing the timing of outdoor air intake reduce indoor concentrations of traffic-related pollutants in schools? *Indoor Air*. 2016;26:687–701. **Medline:26340686 doi:10.1111/ina.12252**
- 73 Sá JP, Branco P, Alvim-Ferraz MCM, Martins FG, Sousa SIV. Evaluation of Low-Cost Mitigation Measures Implemented to Improve Air Quality in Nursery and Primary Schools. *Int J Environ Res Public Health*. 2017;14:585. **Medline:28561795 doi:10.3390/ijerph14060585**
- 74 Rufo JC, Madureira J, Paciência I, Aguiar L, Teixeira JP, Moreira A, et al. Indoor air quality and atopic sensitization in primary schools: A follow-up study. *Porto Biomed J*. 2016;1:142–6. **Medline:32258565 doi:10.1016/j.pbj.2016.07.003**
- 75 Parker R, Whitehouse A, Hadaway T, Araujo R, McCowlen C, Foord E, et al. Let's talk air pollution – it's everyone's responsibility. *Arch Dis Child*. 2021;106:A253.
- 76 Zaeh SE, Koehler K, Eakin MN, Wohn C, Diibor I, Eckmann T, et al. Indoor Air Quality Prior to and Following School Building Renovation in a Mid-Atlantic School District. *Int J Environ Res Public Health*. 2021;18:12149. **Medline:34831903 doi:10.3390/ijerph182212149**
- 77 Maher BA, Gonet T, Karloukovski VV, Wang H, Bannan TJ. Protecting playgrounds: local-scale reduction of airborne particulate matter concentrations through particulate deposition on roadside 'tredges' (green infrastructure). *Sci Rep*. 2022;12:14236. **Medline:35987916 doi:10.1038/s41598-022-18509-w**
- 78 Lanza K, Alcazar M, Hoelscher DM, Kohl HW. Effects of trees, gardens, and nature trails on heat index and child health: design and methods of the Green Schoolyards Project. *BMC Public Health*. 2021;21:98. **Medline:33413276 doi:10.1186/s12889-020-10128-2**
- 79 Queiroz Almeida D, Paciência I, Moreira C, Cavaleiro Rufo J, Moreira A, Santos AC, et al. Green and blue spaces and lung function in the Generation XXI cohort: a life-course approach. *Eur Respir J*. 2022;60:2103024. **Medline:35896209 doi:10.1183/13993003.03024-2021**
- 80 Arar M, Jung C. Improving the Indoor Air Quality in Nursery Buildings in United Arab Emirates. *Int J Environ Res Public Health*. 2021;18:12091. **Medline:34831846 doi:10.3390/ijerph182212091**
- 81 International Federation of Red Cross and Red Crescent Societies. Heatwave Guide for Cities. IFRC; 2020. Available: <https://www.ifrc.org/document/heat-wave-guide-cities>. Accessed: 5 August 2024.
- 82 Health Canada. Reducing Urban Heat Islands To Protect Health in Canada. Ottawa, Canada: Health Canada; 2020. Available: <https://www.canada.ca/content/dam/hc-sc/documents/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada/Reducing-Urban-Heat-EN.pdf>. Accessed: 5 August 2024.
- 83 United Nations Environment Programme. Beating the Heat: A Sustainable Cooling Handbook for Cities. Nairobi, Kenya: UNEP; 2021. Available: <https://www.unep.org/resources/report/beating-heat-sustainable-cooling-handbook-cities>. Accessed: 5 August 2024.
- 84 Natural Resources Defense Council. City resilience toolkit: response to deadly heat waves and preparing for rising temperatures. 2016. Available: <https://www.nrdc.org/sites/default/files/ahmedabad-resilience-toolkit.pdf>. Accessed: 5 August 2024.
- 85 Global Cool Cities Alliance. A Practical Guide to Cool Roofs and Cool Pavements. Global Cool Cities Alliance. 2012. Available: https://www.coolrooftoolkit.org/wp-content/pdfs/CoolRoofToolkit_Full.pdf. Accessed: 5 August 2024.
- 86 Araujo OR, Araujo MC. The zero impact of the Vehicle Inspection Program on public health in São Paulo, SP. *Rev Saude Publica*. 2020;54:84. **Medline:32844984 doi:10.11606/s1518-8787.2020054001856**

- 87 Estrella B, Sempértegui F, Franco OH, Cepeda M, Naumova EN. Air pollution control and the occurrence of acute respiratory illness in school children of Quito, Ecuador. *J Public Health Policy*. 2019;40:17–34. [Medline:30377300](#) [doi:10.1057/s41271-018-0148-6](#)
- 88 Gehrsitz M. The effect of low emission zones on air pollution and infant health. *J Environ Econ Manage*. 2017;83:121–44. [doi:10.1016/j.jeem.2017.02.003](#)
- 89 Inoue T, Nunokawa N, Kurisu D, Ogasawara K. Particulate air pollution, birth outcomes, and infant mortality: Evidence from Japan's automobile emission control law of 1992. *SSM Popul Health*. 2020;11:100590. [Medline:32551355](#) [doi:10.1016/j.ssmph.2020.100590](#)
- 90 Griffiths CJ, Mudway I, Wood H, Marlin N, Dundas I, Walton R, et al. P180 Impact of the London low emission zone on children's respiratory health: a sequential yearly cross sectional study 2008–2014. *Thorax*. 2016;71:A182. [doi:10.1136/thoraxjnl-2016-209333.323](#)
- 91 Mudway IS, Dundas I, Wood HE, Marlin N, Jamaludin JB, Bremner SA, et al. Impact of London's low emission zone on air quality and children's respiratory health: a sequential annual cross-sectional study. *Lancet Public Health*. 2019;4:e28–40. [Medline:30448150](#) [doi:10.1016/S2468-2667\(18\)30202-0](#)
- 92 Willis MD, Hill EL, Kile ML, Carozza S, Hystad P. Assessing the effectiveness of vehicle emission regulations on improving perinatal health: a population-based accountability study. *Int J Epidemiol*. 2021;49:1781–91. [Medline:33485273](#) [doi:10.1093/ije/dyaa137](#)
- 93 Giannadaki D, Lelieveld J, Pozzer A. Implementing the US air quality standard for PM2.5 worldwide can prevent millions of premature deaths per year. *Environ Health*. 2016;15:88. [Medline:27552859](#) [doi:10.1186/s12940-016-0170-8](#)
- 94 Maji KJ, Arora M, Dikshit AK. Premature mortality attributable to PM2.5 exposure and future policy roadmap for 'airpocalypse' affected Asian megacities. *Process Saf Environ Prot*. 2018;118:371–83. [doi:10.1016/j.psep.2018.07.009](#)
- 95 Castro A, Künzli N, Götschi T. Health benefits of a reduction of PM10 and NO2 exposure after implementing a clean air plan in the Agglomeration Lausanne-Morges. *Int J Hyg Environ Health*. 2017;220:829–39. [Medline:28411064](#) [doi:10.1016/j.ijheh.2017.03.012](#)
- 96 Yang M, Chou S-Y. The impact of environmental regulation on fetal health: Evidence from the shutdown of a coal-fired power plant located upwind of New Jersey. *J Environ Econ Manage*. 2018;90:269–93. [doi:10.1016/j.jeem.2018.05.005](#)
- 97 DeCicca P, Malak N. When good fences aren't enough: The impact of neighboring air pollution on infant health. *J Environ Econ Manage*. 2020;102:102324. [doi:10.1016/j.jeem.2020.102324](#)
- 98 Perera F, Cooley D, Berberian A, Mills D, Kinney P. Co-Benefits to Children's Health of the U.S. Regional Greenhouse Gas Initiative. *Environ Health Perspect*. 2020;128:77006. [Medline:32749866](#) [doi:10.1289/EHP6706](#)
- 99 Payne-Sturges DC, Marty MA, Perera F, Miller MD, Swanson M, Ellickson K, et al. Healthy Air, Healthy Brains: Advancing Air Pollution Policy to Protect Children's Health. *Am J Public Health*. 2019;109:550–4. [Medline:30789769](#) [doi:10.2105/AJPH.2018.304902](#)
- 100 Banerjee R, Maharaj R. Heat, infant mortality, and adaptation: Evidence from India. *J Dev Econ*. 2020;143:102378. [doi:10.1016/j.jdeveco.2019.102378](#)
- 101 Rahman MM, McConnell R, Schlaerth H, Ko J, Silva S, Lurmann FW, et al. The Effects of Coexposure to Extremes of Heat and Particulate Air Pollution on Mortality in California: Implications for Climate Change. *Am J Respir Crit Care Med*. 2022;206:1117–27. [Medline:35727303](#) [doi:10.1164/rccm.202204-0657OC](#)
- 102 Fatouros S, Capetola T. Examining Gendered Expectations on Women's Vulnerability to Natural Hazards in Low to Middle Income Countries: A critical Literature Review. *Int J Disaster Risk Reduct*. 2021;64:102495. [doi:10.1016/j.ijdrr.2021.102495](#)
- 103 Mosadeghrad AM, Isfahani P, Eslambolchi L, Zahmatkesh M, Afshari M. Strategies to strengthen a climate-resilient health system: a scoping review. *Global Health*. 2023;19:62. [Medline:37641052](#) [doi:10.1186/s12992-023-00965-2](#)
- 104 Gabrysch S, Lema C, Bedriñana E, Bautista MA, Malca R, Campbell OM, et al. Cultural adaptation of birthing services in rural Ayacucho, Peru. *Bull World Health Organ*. 2009;87:724–9. [Medline:19784454](#) [doi:10.2471/BLT.08.057794](#)
- 105 Makondo CC, Thomas DSG. Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. *Environ Sci Policy*. 2018;88:83–91. [doi:10.1016/j.envsci.2018.06.014](#)
- 106 Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z. *JBI Manual for Evidence Synthesis 2024*. Available: <https://synthesismanual.jbi.global>. Accessed: 5 August 2024.