

Review

Mapping multilevel adaptation response to protect maternal and child health from climate change impacts: A scoping review

Dinesh Bhandari,^{1,2} Eddie Robinson,¹ Wendy Pollock,¹ Jessica Watterson,^{3,4} Tin Tin Su,⁵ and Zerina Lokmic-Tomkins^{1,2,6,*}

¹School of Nursing and Midwifery, Monash University, Clayton, VIC, Australia

²Monash Health and Climate Initiative, Monash University, Clayton, VIC, Australia

³School of Health and Social Development, Faculty of Health, Deakin University, Burwood, VIC, Australia

⁴Jeffrey Cheah School of Medicine and Health Sciences, Monash University Malaysia Campus, Bandar Sunway, Selangor, Malaysia

⁵South East Asia Community Observatory (SEACO), Jeffrey Cheah School of Medicine and Health Sciences, Monash University Malaysia Campus, Bandar Sunway, Selangor, Malaysia

⁶Senior author

*Correspondence: zerina.tomkins@monash.edu

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SUMMARY

Anthropogenic climate change attributed increases in air pollution, rising temperatures, and extreme weather events are linked to a higher risk of adverse pregnancy and birth outcomes, necessitating interventions to protect maternal and child health. This scoping review mapped multilevel adaptation strategies implemented to protect maternal and child health from climate change effects. Eighteen unique adaptation strategies we identified included educational interventions, risk communication, air purifiers, air cleaning strategies, nutrition supplementation, cash transfer, employment guarantee scheme, community health worker program, chemoprophylaxis, insecticide-treated nests, home and environmental remediation, and bioethanol cooking fuel. Our findings suggest that these adaptation strategies are generally nonspecific and fail to address the specialized needs and unique health risks faced by pregnant women and young children. Prioritizing the involvement of pregnant women, mothers of young children and local healthcare services in developing tailored adaptation interventions is crucial to support climate change adaptation, resilience, and reducing maternal and child health risks.

INTRODUCTION

Anthropogenic climate change attributed increases in air pollution, ambient temperature and extreme weather events,¹ are associated with escalated risk of various birth and pregnancy-related adverse outcomes—stillbirth, low birth weight, preterm birth, and preeclampsia.^{2–6} Developing countries have witnessed approximately 107,888 excess annual pregnancy losses associated with gestational exposure to flood events.⁷ In the United States, ambient heat exposure contributes to approximately 25,000 premature births annually, resulting in over 150,000 lost gestational days.² In flood-prone Bangladesh, between 1988 and 2017, 152,753 excess infant deaths were recorded due to residency in such areas.⁸ Extant research highlights the increased vulnerability of pregnant women and young children, including potential long-term and intergenerational effects of climate change on the offspring's health,^{2,3,5,9,10} underscoring the imperative for public health community to design and implement tailored adaptation interventions to protect maternal and child health from the effects of climate change.

While there is a growing recognition of pregnant women and young children as a vulnerable group to the impacts of climate change,^{2,3} we lack systematic information on effective adaptation strategies to protect health of pregnant women, new mothers and young children from the adverse impacts of climate change.^{11,12} Climate change adaptation is defined as “the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities”.¹³ Even with proactive emission reduction strategies, past emissions will cause persistent warming for decades, necessitating appropriate adaptation measures to protect the health of high-risk populations.^{4,14} An effective adaptation strategy, informed by vulnerability assessments across diverse populations and regions, can mitigate potential health risks by reducing exposure to climate-related hazards and enhancing resilience to adverse outcomes.^{15,16} Literature on adaptation strategies to climate change impacts published between 2013 and 2019 reveals a notable lack of information on interventions specific to maternal and child health.^{11,12,17} Given the increased risk to the wellbeing of pregnant women and young children due to climate change, there is a pressing need to identify and design



effective adaptation strategies to protect their health. Identifying adaptation strategies is crucial to facilitating broader implementation of targeted interventions, aiming to prevent and alleviate adverse pregnancy outcomes while simultaneously promoting the health of young children. The specific objective of this paper, as outlined in the peer reviewed protocol,¹⁸ is to map out multi-level adaptation interventions implemented to protect maternal and child health from the effects of climate change. These interventions may be transferable across different settings depending on cultural acceptability and feasibility.^{18,19}

METHOD DETAILS

A protocol detailing the methods employed in this scoping review and subsequent data analysis plan has been published.¹⁸ In summary, we framed the review using the population, concept and context approach as described by the Joanna Briggs Scoping Review Framework.^{20,21} We followed the five sequential stages: identifying the research question, identifying relevant studies, study selection, data charting, and collating, summarizing and reporting the results.²² We reported our review according to the Preferred Reporting Items for Systematic Review and Meta-Analyses Extension for Scoping Reviews.²³

The study population included pregnant women, women during childbirth or those within five years of giving birth, and children under five years of age as defined in the scoping review protocol.¹⁸ For clarity, we adapted specific definitions of key concepts, namely climate change, adaptation, and mitigation from the sixth assessment report of the Intergovernmental Panel on climate change.¹³ Likewise, we adapted the World Health Organization's definition on maternal and child, which focuses on "the health of women during pregnancy, childbirth and postpartum period; and the health of children under 5 years of age", for the purposes of this review.²⁴

The concept included adaptation interventions implemented to protect maternal and child health from the effects of climate change. Within this review, we assessed impacts of climate change on maternal and child health by employing selected indicators and climate hazards as reported in the recent *Lancet* countdown on health and climate change report.^{18,25} We considered maternal and child health adaptation interventions across diverse socio-economic and cultural contexts without any geographical restrictions.

Database search

Our literature search was conducted across 15 different databases encompassing various fields, including health science, social and behavioral science, education and clinical trials repositories. This comprehensive search was executed using database specific pre-developed search strings.¹⁸ The search strategy was developed, piloted, and finalized after consultation with a subject specific information specialist.¹⁸ Three key concepts: climate change, adaptation, and maternal and child health, along with their corresponding synonyms were combined using the AND operator, and searched using four different platforms (OVID, EBSCOhost, DoPHer, and Global Index Medicus).

Screening of documents and study selection

All articles published until 21st March 2024 were retrieved without imposing any language restrictions and subsequently imported to Covidence software for the initial screening of titles and abstracts using EndNote.²⁶ All articles were screened manually based on the contents of the title and abstract by two independent reviewers (D.B. and Z.L.-T.), using a set of prior inclusion and exclusion criteria as outlined in the [Table 1](#).

Conflicts arising during the review process were resolved through collaborative discussion among the three reviewers (D.B., Z.L.-T., and E.R.), ensuring a comprehensive and consensus-driven approach to address divergent perspectives.

Data extraction and charting

We collected data regarding the characteristics of the study, climate hazards, adaptation interventions, and the impact of interventions on maternal and child health outcomes using a peer-reviewed data collection table.¹⁸ To assess the comprehensiveness of the intervention information provided in the included studies, we employed the template for intervention description and replication (TIDieR) checklist.²⁷ TIDieR is a comprehensive and standardized guide designed to ensure the complete reporting and replicability of interventions in various study types, including trials, case-control studies, and cohort studies.²⁷ This approach enabled us to extract pertinent information on the implementation aspects of the interventions which are crucial for their replication and future refinements. The extracted information on adaptation interventions were categorized into four distinct levels—individual, household, community, and policy-based on their implementation aspects. Narrative synthesis was used to describe key thematic areas related to adaptation response to mitigate maternal and child health risks posed by different climate hazards.

We used R software for data visualization²⁸ and mapped the global distribution of studies included in the final synthesis with their respective climate hazards categories using the R package "rnatualearth".²⁹ R package "pheatmap" was used to generate a heatmap to visualize the relative abundance of adaptation responses against specific climate hazards.³⁰ A Sankey diagram was created using the R package "networkD3",³¹ to illustrate the connections between specific adaptation responses implemented at various levels in response to diverse climate hazards and resulting maternal and child health outcomes.

While our mapping exercise did not primarily focus on evaluating the efficacy of the implemented adaptation response, we extracted information on the reduction in maternal and child health risks that occurred after the implementation of the adaptation response, as reported in the original study. Specifically, we utilized three pre-defined outcome-related pieces of information outlined in the study protocol's data extraction tool¹⁸ (1) what outcomes were measured in the context of climate change and health indicators, (2) how these outcomes were measured, and (3) what the main findings were with reference to the intervention implemented. It is essential to acknowledge that adaptation responses curb the climate change-related risk by reducing vulnerability and exposure to climate hazards. As our data extraction tool did not include specific indicators for assessing changes in vulnerability or exposure, this information of

Table 1. Review framework outlining the inclusion and exclusion criteria

Framework components	Inclusion criteria	Exclusion criteria
Population (P)	Children (<5 years), pregnant women, women during childbirth or those within five years of giving birth	
Concept (C)	Studies reporting adaptation interventions implemented at individual, community or institutional and policy level to protect maternal and child health from climate change impacts. Health impacts in this review refer to any health-related outcomes associated with climate change or climate change-induced hazards (heatwaves, bushfires, floods, hurricanes, and air pollution). For community and policy-level interventions, only those interventions specifically reporting outcomes for the above defined population were included. Studies that did not report subgroup analysis for these populations were excluded. Similarly, for multi-hazard and multi-intervention studies, data were extracted only for the interventions that target the climate hazards and indicators described in the protocol. ¹⁶	Studies were excluded if they did not meet the mentioned inclusion criteria, or if: interventions are not described; do not relate to health outcomes; do not relate to climate change indicators mentioned in the protocol, ¹⁶ report asthma attributed to factors other than air pollution (indoor and ambient), wildfire, and pollens and mold spore's exposure; report mitigation measures targeting emission reduction (greenhouse gases and particulate matter); interventions that propose the use of biomass or fossil fuel-based solutions.
Context (C)	Diverse cultural contexts across the continents (broadly: American, European, Asian, Oceanian, Middle East or African culture) and economic settings (high-income, low-middle-income or low-income countries combined with low resource territories) without any geographical restrictions.	
Types of studies	Randomized controlled designs, quasi-experimental designs, ecological studies, observational studies and systematic reviews and meta-analysis. Qualitative and quantitative studies	Full text not available; articles are letters to the editor, commentaries, and reviews other than systematic reviews.

intervention efficacy relies on changes in health outcomes compared to their baseline measurements, when available.

RESULTS

Our database searches yielded a total of 27,506 articles, of which 11,903 were duplicates. After screening the titles and abstracts of the remaining 15,603 non-duplicate articles, we retrieved 90 articles for full text review and found 21 articles that met our inclusion criteria for this scoping review (Figure 1). All included studies were quantitative and reported in detail in *supplementary file*. They included randomized controlled trials ($n = 9$, 43%),^{32–40} quasi-experimental designs ($n = 5$, 24%),^{41–45} cohort studies ($n = 6$, 28%),^{46,47–51} and ecological modeling ($n = 1$, 5%).⁵² These studies were conducted in diverse settings, with adaptation interventions implemented across different socio-economic, cultural, and resource contexts on 4 different continents, including North America ($n = 5$, 24%),^{40,41,43,48,50} South America ($n = 1$, 5%),³⁵ Africa ($n = 5$, 24%),^{37,42,47,49,51} and Asia ($n = 10$, 47%),^{32–34,38,39,44–47,52} (Figure 2).

Synthesis of multilevel interventions implemented as climate change adaptation response to protect maternal and child health

We identified 18 unique climate change adaptation strategies targeted to protect maternal and child health, outlined in Table 2. These strategies were executed to reduce maternal and child health risks from nine different climate hazard categories, inclusive of ambient air pollution,^{32,33,35,36,39,45,52} indoor air pollution,^{37,40,48–50} extreme weather events,⁴³ extreme heat,^{38,46,51}

environmental allergens,⁴⁸ flood,^{42,44} tornado,³⁴ general climate change,^{41,53} and rainfall anomaly⁴⁷ (Figure 3). We further sorted the adaptation interventions into distinct categories based upon the intervention delivery unit (actors responding to hazards) or implementation levels as individual, household, community, and population level and linked these interventions to targeted populations (pregnant women, women within five years of giving birth, parents and caregivers, and children under 5 years) and subsequent maternal and child health outcomes (Figure 4).

The interventions included educational intervention ($n = 5$, 28%),^{38,43,44,49,50} risk communication and text messaging ($n = 2$, 11%),^{36,41} air purifier and air cleaning strategy ($n = 6$, 33%),^{32,33,39,40,45,52} nutrition supplementation ($n = 1$, 6%),³⁴ cash transfer ($n = 1$, 6%),⁵¹ employment guarantee scheme ($n = 1$, 6%),⁴⁶ community health worker program ($n = 1$, 6%),⁴⁶ chemoprophylaxis against infection ($n = 1$, 6%),⁴² long lasting insecticide treated nets ($n = 1$, 6%),⁴⁷ home and environmental remediation ($n = 3$, 17%),^{35,48,50} and bioethanol cooking fuel ($n = 1$, 6%),³⁷ often implemented in the form of packages, and against multiple climate hazards to protect maternal and child health (Figure 3). Some studies featured multiple interventions, and some of these interventions recurred across various studies. Only one study (5%) used a co-design approach with local stakeholders for an integrated environmental home-based intervention package to improve child health and test cultural acceptability of the intervention.³⁵

Individual level adaptation response

Half of the adaptation interventions (50%) to protect maternal and child health from impacts of climate change was implemented at

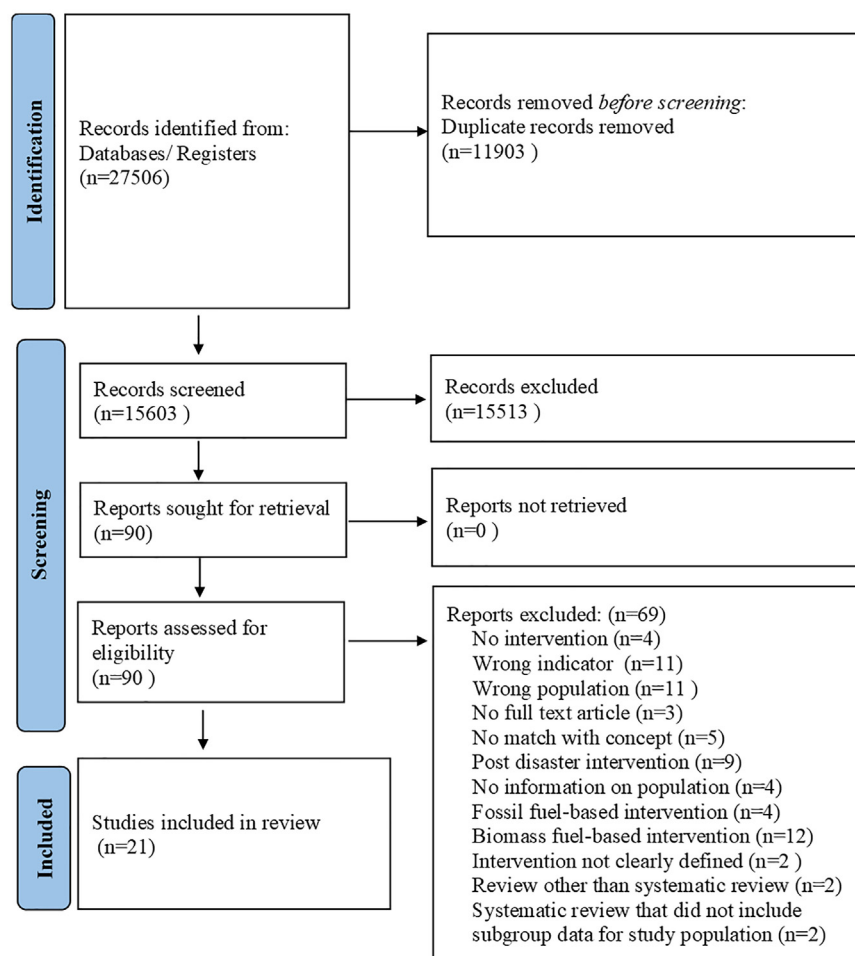


Figure 1. PRISMA diagram of the literature selection process

*After the full text screening, two systematic reviews were not included in the final result synthesis. The first review was omitted because it did not find any intervention related to maternal and child health outcomes.¹² In contrast, the second systematic review did involve adaptation interventions related to asthma outcomes among children. However, the primary studies included in this review did not report separate data specific to children under 5 years.⁵³

sented a clear rationale and theoretical framework, provided details on the materials used for the implementation of these interventions and outlined the intervention procedures.^{34,36,40–43,47,49} Four (19%) studies provided detailed information about the intervention providers, including their expertise, background and specific training relevant to the adaptation response they delivered.^{40,42,43,49} Two (10%) studies did not provide information about the specific location where the intervention took place,^{34,36} and one (5%) study did not describe the frequency of intervention delivery or the duration and intensity of the implemented adaptation response.⁴⁰ The chemoprophylaxis response⁴² and the mobile phone-based alert messages³⁶ interventions were tailored according to the needs of participants and the severity of

the individual level.^{34,36,40–43,47,49} The nine (50%) unique individual-level adaptation responses described in eight (38%) studies included a narrative approach to communicate climate change risks,⁴¹ the use of antimalarial drugs as chemoprophylaxis during floods,⁴² the deployment of long-lasting insecticide nets to reduce uncomplicated malaria during extreme rainfall,⁴⁷ nutrition supplementation with Vitamin A to promote health and wellbeing during tornado,³⁴ nurse-led disaster preparedness interventions,⁴³ mobile phone-based alert messages,³⁶ a midwife-led educational and behavioral change initiative,⁴⁹ and a low-cost education and air filtration intervention package.⁴⁰ Some of these interventions were nested together and delivered as a package, leading to overlap in the interventions among different studies. The primary goal of these interventions was to improve maternal and child health outcomes, including reducing rates of lower respiratory tract infection,⁴⁰ preventing malaria,^{42,47} improving birth outcomes (low birth weight, length at birth, preterm birth),³⁴ reducing all-cause mortality, and enhancing emergency preparedness.⁴³ Additionally, some of these interventions aimed to enhance perceived knowledge^{41,49} and modify behaviors in response to several climate hazards.³⁶

After mapping with the TiDieR checklist,²⁷ we observed that all eight (38%) studies provided a name for the intervention and pre-

climate hazard exposure. The randomized controlled trials implementing individual-level adaptation interventions described participants' fidelity and adherence to the implemented adaptation measures. For more details, please see the *supplementary file*.^{34,36,40}

Household-level adaptation response

A total of five unique household-level adaptation responses (28%), described in eight (38%) studies, were implemented to improve maternal and child health outcomes, specifically addressing respiratory tract infection and diarrheal diseases,^{35,50} early childhood asthma,⁴⁸ inflammatory biomarkers during pregnancy,³⁷ and children's cognitive performance.³⁹ These adaptation responses comprised the deployment of various strategies: portable high efficiency particulate air (HEPA) filter air cleaners to improve ambient air pollution,^{32,33,39} home remediation combined with education on air quality,⁵⁰ bioethanol cooking fuel to reduce air pollution-related inflammatory response,³⁷ a low-cost intervention package to improve the indoor environment,⁴⁸ and an integrated environmental home-based intervention package to improve water, sanitation and hygiene (WASH), and air quality.³⁵ All of these interventions were exclusively designed to protect the health of pregnant women and young children

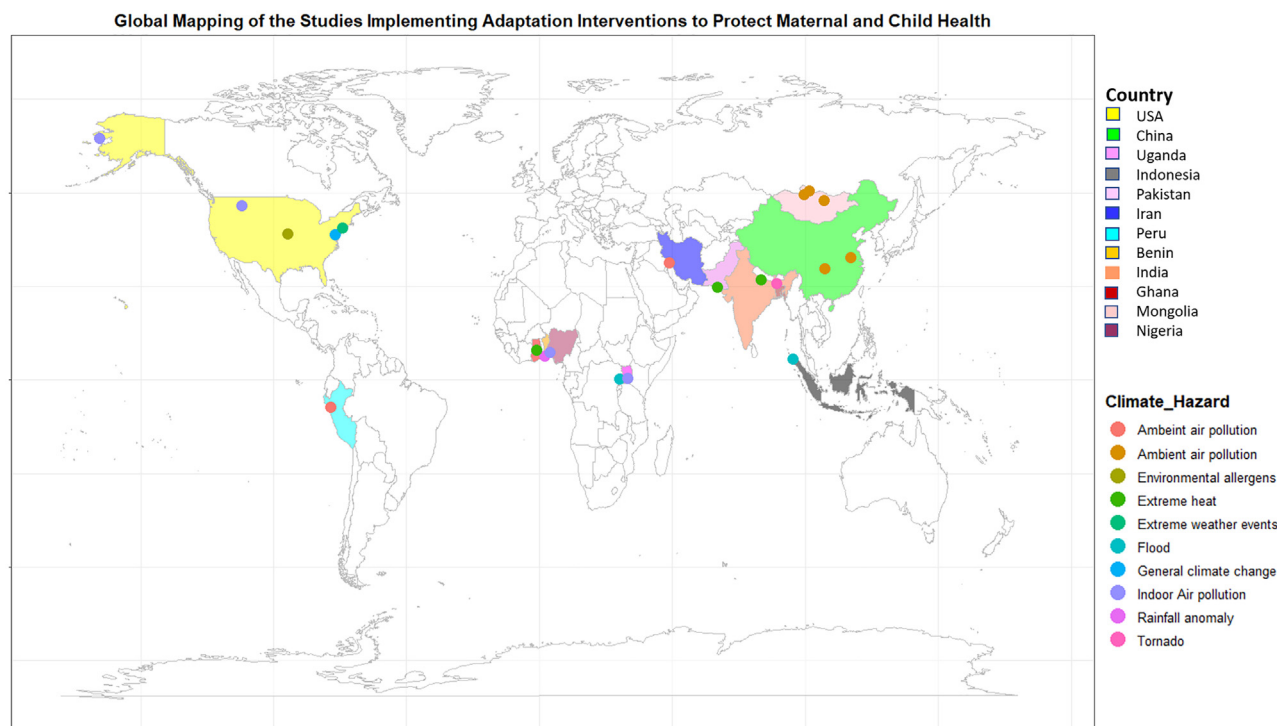


Figure 2. Geographic distribution of studies included in the final evidence synthesis (N = 21)

from the adverse effects of air pollution. While HEPA filter air cleaners were primarily deployed to mitigate the health impacts of ambient air pollution,^{32,33,35,39} bioethanol-based cooking fuel, home remediation and the low-cost intervention package targeted indoor air pollution and environmental allergens.^{37,48,50}

Using the TIDieR checklist, we determined that seven studies (33%)^{32,33,35,37,39,48,50} implementing five unique household level interventions thoroughly outlined the procedural details of the interventions, including the materials provided to the participants. Nevertheless, in a randomized controlled trial investigating the effectiveness of bioethanol-based cooking fuel in reducing inflammatory biomarkers during pregnancy in response to indoor air pollution exposure, there was a lack of description regarding the expertise and background of personnel involved in delivering the intervention.³⁷ The randomized controlled trials investigating the efficacy of HEPA filter air cleaners in reducing exposure to ambient air pollution did not provide sufficient information on participants' fidelity and adherence to the interventions.^{32,33,39}

Community-level adaptation response

Among the 18 unique adaptation responses to protect maternal and child health from climate change impacts identified through the review, only one community-level adaptation response, described in a single (5%) study, was implemented.³⁸ This study executed a community-based educational intervention with the objective of protecting human health against the impacts of extreme heat. The study population included the whole of the community, all age groups, and it provided separate estimates specifically pertaining to children under five years of age. This

educational intervention was tested through a cluster-randomized controlled trial, delivered by community health workers who assumed the role of educators. During the interactive sessions, which extended to household and neighborhood visits, participants were educated about the risk factors and symptoms associated with heat-related illnesses. They were also equipped with information about the preventive measures, primarily disseminated through "heat emergency awareness and treatment" (HEAT) pamphlets and posters.³⁸ The study reported all the components as per TIDieR checklist, except for one crucial aspect—the specifics regarding participants' fidelity and adherence to the intervention. Nevertheless, the study's findings have the potential for partial replication and translation in different settings.^{27,38}

Policy-level adaptation response

Among all of the maternal and child health adaptation strategies identified, five (28%) interventions, described in four studies,^{45,46,51,52} were targeted at the policy level. Three unique adaptation strategies described in two studies, from India and Ghana aimed at mitigating the health consequences of extreme heat exposure among neonates and infants.^{46,51} A study conducted in India assessed the effectiveness of two government-led strategies, namely the National Rural Employment Guarantee Act (NREGA) and the Accredited Social Health Activists (ASHA) program, in reducing infant mortality associated with extreme heat.⁴⁶ This study utilized regression-based analysis to assess the effectiveness of these two programs independently at the individual level, while also adjusting for their mutual effects.

Table 2. Characteristics of the included studies

Author, year	Study design	Country	Aims/Objectives	Study population	Climate hazard	Interventions/adaptation strategies	What were the main findings with reference to the intervention implemented?
Adebayo et al., 2020 ⁴¹	Randomized experiment	USA	To test the effectiveness of brief educational interventions on climate change health risks.	Pregnant women	General climate change	Narrative way of risk communication the impacts of climate change on maternal and child health	Narrative information delivery was superior to didactic information delivery in increasing pregnant women's knowledge, to protect maternal and child health from climate change impacts.
Barn et al., 2018 ³²	Randomized controlled trial	Mongolia	To test if HEPA cleaner use at home from early pregnancy until childbirth was associated with improvements in fetal growth.	Pregnant women	Ambient air pollution	Portable HEPA filter air cleaner during pregnancy and fetal growth	Overall, among all births portable HEPA filter was not associated with improvements in fetal growth. It was associated with greater birth weight only among term births.
Boyce et al., 2022 ⁴²	Quasi-experimental design	Uganda	To test the efficacy of a mass drug administration program using Dihydroartemisinin-piperaquine in reducing excess malaria incidence associated with flood among children.	Children less than 12 years of age	Flood	Dihydroartemisinin-piperaquine	Overall, the incidence of malaria following the intervention was significantly lower in the intervention village compared to the control village.
Damien et al., 2016 ⁴⁷	Longitudinal cohort	Benin	To test the effectiveness of long-lasting insecticide net in prevention of uncomplicated clinical malaria among children.	Children <5 years	Rainfall anomaly	Long lasting insecticide nets (LLIN)	The use of LLINs was associated with significant protection against uncomplicated clinical malaria episodes among children in one of the study sites and partially protective in the other site.
Enkhbat et al., 2021 ³³	Randomized controlled trial	Mongolia	To quantify the impact of reducing indoor PM using portable HEPA filter air cleaners during pregnancy on behavioral problems in children.	Pregnant women	Ambient air pollution	Portable HEPA filter air cleaner	Overall, there was no benefit of reducing indoor particulate air pollution during pregnancy on parent-reported behaviors in children.

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Table 2. Continued

Author, year	Study design	Country	Aims/Objectives	Study population	Climate hazard	Interventions/adaptation strategies	What were the main findings with reference to the intervention implemented?
Gunnsteinsson et al., 2022 ³⁴	Cluster randomized controlled trial	Bangladesh	To evaluate the efficacy of a nutritional supplementation program in safeguarding the developing fetus and infants from the negative health impacts associated with extreme weather event.	Infants	Tornado	Vitamin A supplementation	In the control group, high rate of adverse birth outcomes and fever incidence were reported but no impacts were observed in the intervention group.
Hartinger et al., 2016 ³⁵	Cluster randomized controlled trial	Peru	To evaluate the efficacy of integrated environmental home-based intervention package (IHIP) on reducing acute diarrheal illness and acute respiratory infections among children and its effect on child growth.	Children less than 36 months old	Ambient air pollution	Integrated environmental home-based intervention package consisting of improved solid-fuel stoves, kitchen sinks, solar disinfection of drinking water and hygiene promotion.	Children in the intervention arm showed reduction in diarrhea and respiratory tract infection compared to control group. No difference was observed between the intervention and control arm for anthropometric measurements.
Heagele et al., 2022 ⁴³	Quasi-experimental design	USA	To increase the reach of nurse led health emergency plan intervention to vulnerable populations admitted in a hospital setting.	Parents and caregivers	Extreme weather events	Nurse Taking on Readiness Measures (N-TORM) is a nurse led HEP intervention	There was a significant increase in disaster preparedness level of the participants after the intervention.
Jasemzadeh et al., 2018 ³⁶	Randomized controlled trial	Iran	To evaluate the impact of extended parallel process model based short messages on protective behaviors of pregnant women against air pollution.	Pregnant women	Ambient air pollution	EPPM-based mobile phone text messages	The study reported effectiveness of mobile phone text messaging intervention to promote protective behaviors among pregnant women in dealing with air pollution.
Johnson et al., 2009 ⁴⁸	Longitudinal cohort	USA	To evaluate the efficacy of simple low-cost home interventions in improving the health of children with asthma.	Asthmatic children under aged 2–17 years	Environmental allergens and indoor air pollution	Low-cost intervention package to improve indoor environment	Overall, there was a significant reduction in allergy attack among the participants following all three interventions, individual and combined. (Continued on next page)

Table 2. Continued

Author, year	Study design	Country	Aims/Objectives	Study population	Climate hazard	Interventions/adaptation strategies	What were the main findings with reference to the intervention implemented?
Nantanda et al., 2019 ⁴⁹	Implementation research	Uganda	To develop an education program aiming to teach about the dangers of biomass smoke and how to reduce its exposure, to influence pregnant women, and young children's attitudes and behaviors.	Pregnant women	Indoor air pollution	Midwife-led health education strategy to reduce exposure to biomass smoke among pregnant women	The educational program was successful in changing knowledge of mothers about the dangers of biomass smoke exposure to their health and the health of their children.
Olopade et al., 2017 ³⁷	Randomized controlled trial	Nigeria	To determine the impact of transition from traditional firewood/kerosene stove to bioethanol burning stove on inflammatory biomarkers in pregnant women.	Pregnant women	Indoor air pollution	Bioethanol cooking fuel to reduce inflammatory response during pregnancy	Overall, the mean change in concentration of serum inflammatory biomarkers post intervention across the two treatment arms was not statistically significant.
Rachmawati et al., 2021 ⁴⁴	Quasi-experimental design	Indonesia	To analyze the effect of disaster management education on the preparedness of mothers under five in Aceh province, Indonesia	Mothers of children under 5 years	Flood	Disaster management education	There was improvement in the level of knowledge, attitude and preparedness among the participants about disaster following the educational intervention.
Razzak et al., 2022 ³⁸	Cluster randomized controlled trial	Pakistan	To evaluate the impact of community health workers-led community education on heat-related health outcomes and heat literacy.	Children under five	Extreme heat	Community health worker led heat education program	All causes hospital visit among the intervention group was significantly lower compared to control group. Greater improvement in the knowledge, attitude and practise was observed among the intervention group than the control group.

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Table 2. Continued

Author, year	Study design	Country	Aims/Objectives	Study population	Climate hazard	Interventions/adaptation strategies	What were the main findings with reference to the intervention implemented?
Shao et al., 2022 ⁴⁵	Quasi-experimental design	China	To evaluate the impact of China's SO ₂ emission trading system policy on infant's health.	Infants	Ambient air pollution	Chinese government SO ₂ emission trading system (ETS) policy	The implementation of the SO ₂ ETS pilot policy significantly and persistently reduced infant mortality after controlling the county fixed effect and the year fixed effect.
Singleton et al., 2018 ⁵⁰	Prospective cohort	USA	To evaluate the impact of home remediation and household education on indoor air quality, respiratory symptoms, and lower respiratory tract infections visits among children with chronic lung conditions.	Children aged 1–12 years	Indoor air pollution	Home remediation and household education on air quality	There was an overall decrease in outpatient medical visits, acute respiratory infections visits, and lower respiratory tract infections visits for all household children.
Ulziikhuu et al., 2022 ³⁹	Randomized controlled trial	Mongolia	To quantify the impact of reducing exposure to particulate matter during pregnancy on children's cognitive performance at 4 years of age.	Pregnant women	Ambient air pollution	Portable HEPA filter air cleaner	Overall, the study reported that reducing PM air pollution exposure during pregnancy could be beneficial for cognitive development of children (measured at 4 years of age).
Walker et al., 2022 ⁴⁰	Randomized controlled trial	USA	To evaluate the impact of low-cost educational and air filtration interventions on childhood lower-respiratory tract infection and indoor PM _{2.5} concentration in homes with wood stoves.	Children <5 years	Indoor air pollution	Low-cost educational and air filtration interventions	Overall, the study results revealed that neither education intervention nor the filtration intervention substantially reduced lower respiratory tract infections in study children relative to the control arm. (Continued on next page)

Table 2. Continued

Author, year	Study design	Country	Aims/Objectives	Study population	Climate hazard	Interventions/adaptation strategies	What were the main findings with reference to the intervention implemented?
Wang et al., 2022 ⁵²	Observational (Modeling)	China	To evaluate the impact of Air Clean Plan and carbon mitigation measures on health outcomes	All ages including separate reporting for children under five	Ambient air pollution	Air Clean Plan (ACP)	The number of premature deaths attributable to ambient PM2.5 pollution decreased by 0.07 million from 1.35 million to 1.28 million in the APPCAP (2014–2017) and showed continuous declining trend. However, there was an overall increase in the proportion of death due to lower-respiratory tract infection by 0.58%. This included the premature death of 3340 under five years children per year, attributed to particulate matter exposure.
LaPointe et al., 2024 ⁵¹	Retrospective cohort	Ghana	To explore the association between prenatal temperature exposures and low birth weight and evaluate the impact of cash transfer scheme on the association.	Pregnant and lactating women	Extreme heat	Unconditional cash transfer to reduce childhood stunting	Among comparison infants, weekly average temperatures greater than 30°C were associated with increased odds of low birth weight but these associations were null among the intervention infants.
Banerjee et al., 2020 ⁴⁶	Retrospective cohort	India	To estimate the effect of high temperature <i>in utero</i> on infant mortality and evaluate the efficacy of public programs/policies as possible adaptation strategies to high temperatures.	pregnant women	Extreme heat	National Rural Employment Guarantee Act (NREGA), an economic support program and Accredited Social health Activists (ASHA), a Community Health Worker program	At individual level implementation of both NREGA and ASHA program were associated with decrease in infant mortality due to hot days <i>in Utero</i> during the study period for rural India.

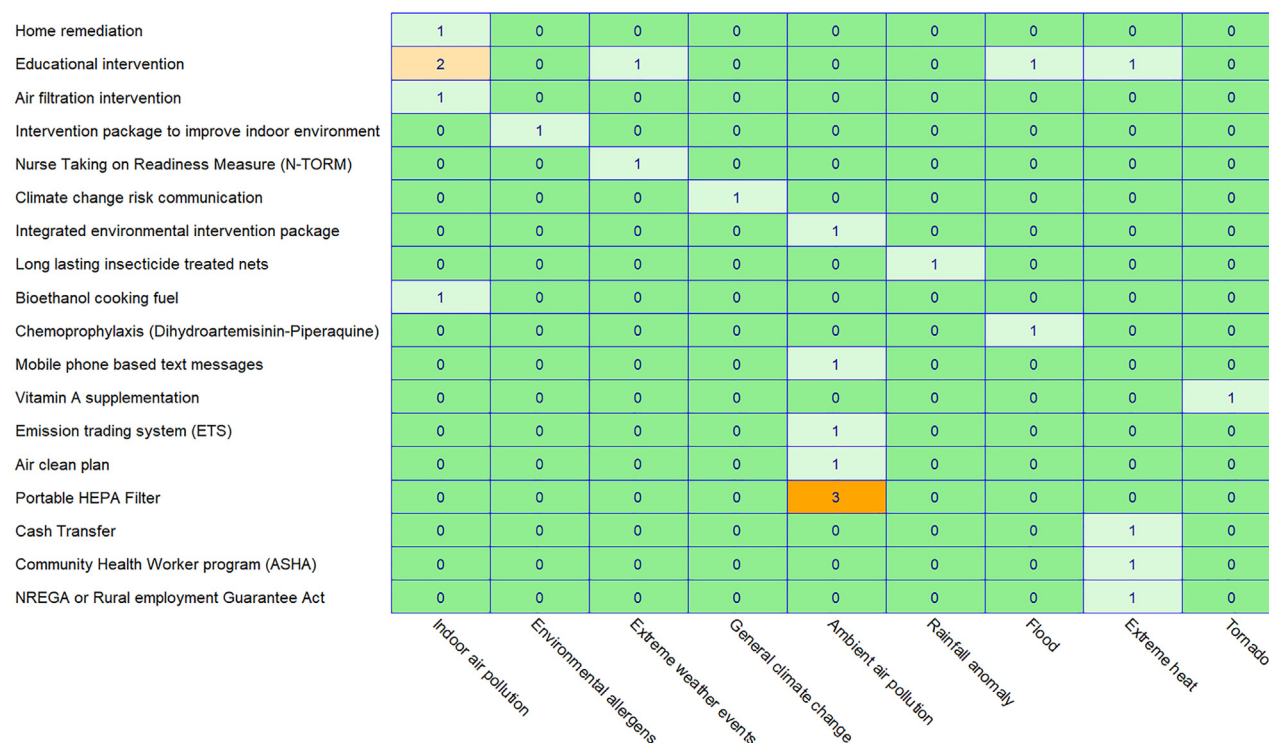


Figure 3. Heatmap of various adaptation interventions targeted against different climate hazards, identified from the included studies (N = 21)

Meanwhile, a study in Ghana investigated the potential of an unconditional cash transfer policy called the Livelihood Empowerment Against Poverty (LEAP) 1000 as an intervention for adapting to extreme heat, aiming to improve birth outcomes among neonates.⁵¹ Here the cohort was stratified into cases and controls based on the date of intervention initiation. The efficacy of the policy was evaluated through regression-based analysis including the intervention and control groups.

The remaining two adaptation strategies were implemented to protect the health impacts of ambient air pollution in China.^{45,52} These two strategies were enforced by the Chinese government at the national level through the SO₂ emission trading system⁴⁵ and a comprehensive Air Clean Plan and carbon mitigation measures.⁵² The first study, which explored the impact of SO₂ emission trading system on infant's health, employed a quasi-experimental design using the differences-in-differences approach to estimate the effect of the adaptation policy.⁴⁵ Meanwhile, the study investigating health gains due to Air Clean Plan employed an ecological modeling approach that utilized index decomposition method to compute changes in premature deaths attributable to fine particulate matter (PM_{2.5}).⁵² This study assessed the changes in premature deaths due to lower-respiratory tract infection among children under five years of age in response to the Air Clean Policy.⁵² Notably, all four (19%) studies^{45,46,51,52} only partially reported the components stipulated in the TiDieR checklist, as information pertaining to the procedures involved and materials used for mandating these policies were inadequately reported.

Among the 21 studies included in the review, one (5%) study evaluating the change in disaster preparedness level among mothers of children under five years old, following disaster management education in response to flood events did not report the unit of intervention delivery.⁴⁴ Although the study reported improvement in the participants' knowledge, attitude and readiness related to disaster preparedness after the delivery of the educational intervention, the study insufficiently described the intervention components as per TiDieR checklist.

Evidence of maternal and child health risk reduction due to the implemented adaptation responses

Among the 21 included studies implementing 18 different maternal and child health adaptation strategies, the majority demonstrated positive changes in the selected maternal and child health outcomes, with few exceptions. The four (19%) studies implementing educational adaptation responses, reported a positive change in knowledge, attitude and practises related to maternal and child health impacts of climate change.^{38,43,44,49} These responses were assessed against diverse maternal and child health-related outcomes including reductions in lower respiratory tract infection,⁴⁰ changes in all-cause mortality and emergency department visits,³⁸ and changes in knowledge, preparedness and practices.^{43,44,49} However, the educational intervention was not effective in reducing the lower respiratory tract infection rates among children caused by exposure to indoor air pollution.⁴⁰

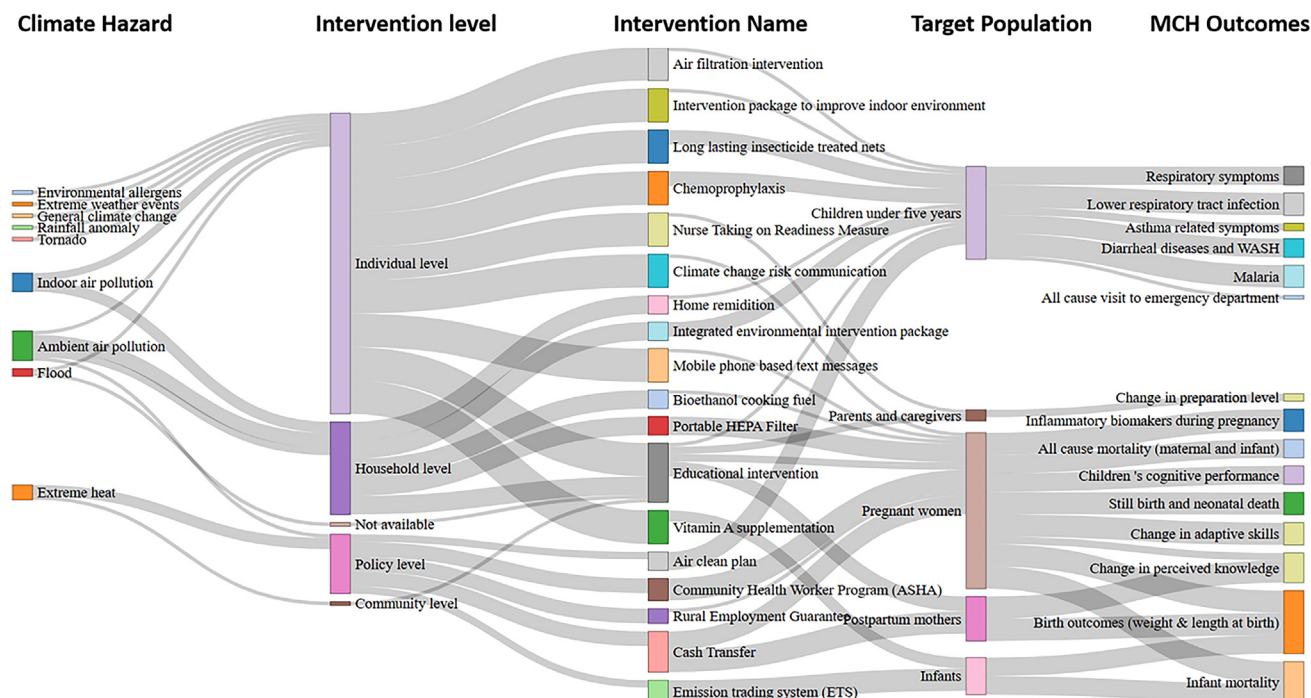


Figure 4. Sankey diagram summarizing the major findings of the scoping reviews: multilevel adaptation interventions targeted against various climate hazards are linked with population of interest and specific maternal and child health outcomes (N = 21)

Similarly, two (11%) adaptation responses in the category of risk communication, implemented against the climate hazards of ambient air pollution and general climate change, reported positive changes in perceived knowledge and risk assessment capacity.^{36,41} Importantly, changes in health outcomes in the majority of these studies were recorded from self-reported responses by the participants or caregivers, in the case of children. Based on the information provided in the reviewed articles, our analysis indicated mixed results on the efficacy of air purifiers and air cleaning strategies in improving maternal and child health outcomes (lower respiratory tract infection, children's cognitive performance, inflammatory biomarkers, behavioral problems, and adverse birth outcomes), stemming from exposure to indoor and ambient air pollution.^{32,33,37,39,45,52} While installation of HEPA filters during pregnancy was associated with improved cognitive performance of children, measured at four years of age,³⁹ no significant effect was reported for birth-related outcomes such as improvement in fetal growth³² and children's behavioral problems.³³

The introduction of two policy level interventions, the cash transfer scheme and the community health worker program (ASHA) correlated with improved infant health outcomes, showcasing the reduced odds of low birth weight and decreased infant mortality, respectively.^{46,51} However, the Employment Guarantee Act (NREGA) did not significantly impact on health outcomes related to extreme heat exposure for infants.⁴⁶ Interestingly, a policy-level intervention to improve air quality reported an increase in the proportion of deaths due to lower-respiratory tract infection by 0–58%, which included premature deaths among 3340 under five-year-old children

per year, attributable to particulate matter.⁵² Similarly, interventions, such as chemoprophylaxis,⁴² insecticide-treated net use against malarial infections,⁴⁷ and nutritional supplementation³⁴ for improved birth outcomes during extreme weather events were reported to be effective in improving the selected child health outcomes.

DISCUSSION

Our results indicate that available evidence concerning adaptation strategies to protect the health of pregnant women and newborn children is mainly confined to health risks posed by air pollution—ambient and indoor. Although some studies comprised adaptation strategies against other climate hazards like floods, storms, and extreme heat, not all of these adaptation interventions were primarily implemented as a response to protect maternal and child health from climate change impacts. Instead, they were planned as general disaster preparedness efforts that concomitantly offered maternal and child health co-benefits.^{43–45,52} While mitigation is paramount for addressing the root causes and long-term consequences of climate change, adaptation will serve to moderate and avoid harm from future emissions and past residuals.^{4,54} Concerning the health adaptation strategies, one size will not fit all.⁵⁵ As such, the disparities in adaptational capacity against climate change among various populations and geographical regions must be accounted for while designing and implementing effective adaptation interventions.⁵⁴

A recent mapping of global literature on climate change and health has revealed a notable disparity in the emphasis placed

on health impact assessment, and insufficient attention on the actual implementation of adaptation interventions, raising concerns about addressing the health needs of high risk groups, including pregnant women and young children.¹⁷ Despite the fact that health risks have consistently taken center stage in the global discussion on climate change, the 2021 global stocktake on climate action found that the majority of adaptation efforts have been primarily deployed within the realm of agriculture and food security.¹¹ Consistent with our findings, the 2021 global stocktake on human adaptation to climate change, while not exclusively focused on health-related adaptation, revealed that the majority (82%) of the identified adaptation strategies were implemented at the individual or household level.¹¹ Meanwhile, a systematic review of evidence concerning the effects of climate change adaptation response on public health within low-and middle-income countries revealed a notable dearth of information on adaptation response focusing on maternal and child health outcomes.¹² A 2022 systematic review assessed climate change adaptation measures for childhood asthma among children under 18 years of age.⁵³ However, examining the individual articles included in the review revealed a lack of data specific to children under five years of age. While this excluded the review from our criteria, it importantly identified ventilation and heating in homes as effective strategies for managing childhood asthma symptoms, particularly in winter. In their 2013 umbrella review of systematic reviews, Bouzid and colleagues assessed the effectiveness of public health interventions to reduce the health impact of climate change.⁵⁶ However, their analysis focused solely on infectious diseases and did not offer any insights on the study population. Similarly, another review which concentrated on national level adaptation strategies of Annex I parties under the United Nations Framework Convention on Climate Change, uncovered an uneven and underdeveloped consideration of the unique needs of vulnerable populations.⁵⁷ In an alarming revelation, the 2011 review reported that none of the 38 contributing countries had recognized health vulnerability within their respective national adaptation strategies.⁵⁷

vFinally, a Cochrane review evaluating the effectiveness of electric fans for reducing adverse health outcomes during heatwaves did not identify any eligible studies.⁵⁸ Ours is the first study to systematically map public health interventions implemented as adaptation responses to protect the health of pregnant women and young children from the effects of climate change. It extends the existing evidence on health adaptation responses and lays a foundation to promote an evidence-based practice framework to climate change adaptation in maternal and child health care.⁵⁹ Our findings indicate that educational interventions for improving pregnant women's knowledge regarding the adverse maternal and child health effects of climate change, as well as their ability to recognize early indicators of heat-related illnesses and adopt proactive practises to mitigate extreme weather events, are not only viable but also practical in resource-constrained settings.^{38,41,43} These interventions can be effectively implemented by leveraging the expertise of healthcare providers such as nurses, midwives, and community healthcare volunteers.

Our findings also highlight that adaptation interventions cannot be universal in nature, and some interventions may not

yield the desired results, and in some cases, they could exacerbate the situation. To illustrate, the use of portable HEPA filters to reduce pregnant women's exposure to ambient particulate matter was associated with a significant risk of late preterm-birth.³² Similarly, the Air Clean Plan implemented by the Chinese government to reduce ambient PM_{2.5} concentrations was associated with an unexplained increase in the proportion of deaths due to lower-respiratory tract infection among children under five years of age.⁵² The absence of explanation for these events may lie in failing to address drivers of vulnerability and poor design of adaptation interventions, which may contribute to maladaptation.¹⁶ Multiple factors, such as cultural acceptability and ethical considerations, aside from the direct consideration of reducing exposure to climate hazards, can significantly influence the efficacy of adaptation strategy and the extent to which people comply with them over time.⁶⁰ For example, we identified interventions that leveraged digital technology to communicate the impacts of air pollution to pregnant women to prompt behavioral change.³⁶ However, the ethical dimension of employing "fear-based messaging" in these risk communication interventions coercing people into specific actions rather than motivating them to make informed decisions, needs to be resolved.³⁶

To advance the adaptation research for protecting maternal and child health from climate change effects, we recommend the following key priorities.

Designing and implementing targeted adaptation interventions

To prevent adverse pregnancy-related outcomes and promote wellbeing of mothers and children in the face of multiple climate hazards, comprehensive maternal and child health adaptation packages are needed. These packages should encompass nutritional support, psychological support, breastfeeding provision, immunization services, prenatal and postnatal care, and sexual and reproductive health needs.⁶¹ These interventions should assess observed impacts and adapt to uncertain climate futures. There is considerable potential in adopting a primary healthcare approach,⁶² and designing specific adaptation strategies to safeguard the wellbeing of developing fetuses, pregnant women and newborn children against climate-related hazards such as extreme heat, floods, and storms. A participatory approach to designing and implementing culturally responsive interventions, involving pregnant women as active decision-makers, will maximize the uptake and efficacy of these adaptation strategies.^{14,19}

To achieve effective translational outcomes through maternal and child health adaptation interventions, foundational cross-cutting elements must be prioritized beyond standard healthcare resources. These elements include environmental modifications, supportive infrastructure development, food and water security, and access to essential social services.¹⁴ For instance, enhancing indoor infrastructure—such as installing reflective curtains, window blinds, and cooling systems—can mitigate heat exposure and improve prenatal and postnatal care.¹⁹ Ensuring food and water security during pregnancy also supports breastfeeding, potentially reducing the carbon footprint associated with formula production.⁶³ The successful implementation and accessibility of these intervention packages will

be strengthened by governance improvements and policy reforms that provide financial support through healthcare systems or local government agencies.⁶⁴

Harnessing the potential of digital technology to enhance adaptation interventions

The disruption of essential maternal and child healthcare services during public health emergencies, such as pandemics and extreme weather events, profoundly impacts the health and wellbeing of pregnant women, mothers, and young children.^{65,66} Taking into consideration the need to reduce digital technologies' carbon footprint,⁶⁷ the development and widespread adoption of appropriate, equitable, accessible, and cost-effective environmentally sustainable digital technology can support climate and health literacy and improve access to and the quality of essential maternal and child health services during public health emergencies, including extreme weather events.⁶⁸

Strengthening health systems' resilience to maintain essential maternal and child health services

A recent WHO scoping review examined interventions reported in peer-reviewed and gray literature on sustainability of vital healthcare services for vulnerable populations, including maternal, newborn, child, adolescent, and older individuals, particularly during disruptive events.⁶⁹ The review highlighted the critical need to strengthen health systems' resilience against unexpected shocks. However, interventions primarily addressed public health crises such as the Ebola virus outbreak, humanitarian emergencies, the COVID-19 pandemic, and natural disasters. Notably, missing are interventions for coping with climate-induced extreme weather events, except for a post typhoon intervention in the Philippines, to maintain maternal health services.⁶⁹ Health systems need to become learning systems, prioritizing preparation and adaptation to climate shocks and public health crises, enhancing access to and quality of perinatal and maternal healthcare.⁷⁰ Essential actions include: (1) *comprehensive assessment of maternal and child health and respective services vulnerability to climate change*; (2) *multidisciplinary adaptation interventions involving stakeholders and local communities*; (3) *securing resources for widespread implementation of adaptation actions*; and (4) *developing learning health systems for continuous monitoring, evaluating and climate-responsive adaptation to protect global maternal and child health*.^{71,72}

Review National Adaptation Plans (NAPs) and Health National Adaptation Plans (H-NAPs)

Scarce attempts have been made to review the health adaptation strategies included in national adaptation policy documents.^{14,57,71} Previous efforts have been incomplete, focusing primarily on developed countries or specific low- and middle-income countries.^{14,57,71,73} It is noteworthy that the priorities in these policy documents (NAPs and HNAPs), will shape a nation's investments in future climate change adaptation.¹⁵ Hence, future evidence synthesis on maternal and child health adaptation should critically evaluate how national adaptation documents address the risks posed by climate change to maternal and child health.

LIMITATIONS OF THE STUDY

Despite comprehensive search strategy, some studies may have overlooked if they are not included in our databases or if they were indexed under specific terms not captured by our search strategy. Since the main objective of our analysis was to scope and map maternal and child health interventions to support adaptation responses to climate change and identify potential gaps in research, we did not perform a quality assessment of the articles. Therefore, we did not evaluate the efficacy of the adaptation interventions in reducing adverse maternal and child health outcomes attributable to climate change, a feature of systematic reviews. Finally, our review did not include gray literature or anecdotal accounts related to emerging areas of research that are currently under investigation.

CONCLUSION

Our analysis has revealed that the adaptation strategies often lack stakeholder involvement in their design and implementation. Consequently, they do not address the specialized needs in culturally responsive way required to mitigate unique health risks faced by pregnant women and young children in the context of a changing climate. Given that the adverse maternal and child health outcomes associated with climate change, such as increased maternal mortality, preeclampsia, gestational diabetes, poor fetal growth, stillbirth, low birth weight, preterm birth, premature rupture of membrane, and stunting, are exclusive to this specific population group. It is imperative to prioritize the development of culturally responsive, tailored adaptation interventions aimed at preventing these outcomes. These interventions should complement efforts to address the more common climate change-associated health risks encountered by the general population.

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AUTHOR CONTRIBUTIONS

Conceptualization: D.B., W.P., J.W., T.T.S., and Z.L.-T.; study design: D.B., W.P., J.W., T.T.S., and Z.L.-T.; literature search: D.B.; data extraction: D.B., E.R., and Z.L.-T.; investigation: D.B., E.R., and Z.L.-T.; formal analysis: D.B. and Z.L.-T.; visualization: D.B.; software: D.B., E.R., and Z.L.-T.; writing—original draft: D.B. and Z.L.-T.; writing—review and editing: D.B., E.R., W.P., J.W., T.T.S., and Z.L.-T.; supervision: Z.L.-T.

DECLARATION OF INTERESTS

Z.L.-T. is a member of the Climate and Health Alliance, Alliance of Nurses for Healthy Environment, World Health Organization Global Community of Practice for Nursing and Midwifery specific to climate change, and Climate Reality Leadership Corps.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at <https://doi.org/10.1016/j.isci.2025.111914>.

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