Exploring the Health Impacts of Extreme Climate Events on Children Under Five in the Sahel: Toward Adaptive Strategies

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This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science in Public Health and Health Equity by Dr Emna Hariz

Declaration:

Where other people's work has been used, this has been carefully acknowledged and referenced in accordance with academic requirements.

The thesis 'Exploring the Health Impacts of Extreme Climate Events on Children Under Five in the Sahel: Toward Adaptive Strategies'is my own work.

Signature: 

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Abstract

Background:

Children under five in the Sahel face disproportionate health risks from extreme climate events (ECE), including extreme heat, droughts, and floods. However, limited evidence synthesizes their impacts on this age group and how emergency responses and program adaptations address their needs.

Methodology:

A literature review of peer-reviewed and grey literature sources, complemented by four key informant interviews with humanitarian health actors from MSF, UNICEF, IFRC, and Action Against Hunger, was conducted. Findings were analyzed by ECE type using the UNICEF climate change and child health framework, focusing on northern Nigeria, Sudan, and Chad.

Results:

Extreme heat was linked to malnutrition, dehydration, birth complications, and disrupted care delivery. Adaptations included vaccination campaigns, early warning systems, and shade infrastructure. Droughts heightened malnutrition (food insecurity) and diarrhea, triggering responses such as mobile clinics, therapeutic feeding programs, and community-led early action protocols. Floods increased malnutrition, diarrhea, malaria, and service disruption. Interventions included mosquito net distribution, mobile health brigades, WASH infrastructure support, and child protection services. Wildfire-related air pollution was associated with increased child mortality. Across contexts, anticipatory action remained limited, while local actors often led first responses. Interventions often miss maternal and mental health needs. ECE preparedness remains ad hoc and poorly integrated.

Conclusion:

ECEs like drought, floods, and extreme heat in the Sahel threaten child health, specifically malnutrition, diarrhoea, and malaria. and all ECEs hamper access to health care. Yet program responses remain reactive and fragmented. Strengthening anticipatory systems and community-based preparedness are critical to protecting children under five in climate-affected regions.

Keywords:

Children under five, Extreme climate events, Health impacts, medical humanitarian organizations, Sahel region

Word Count: 11, 846

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List of Abbreviations

ARIs: Acute Respiratory Infections

ECE: Extreme Climate Events

IFRC: International Federation of Red Cross and Red Crescent Societies

IPCC: Intergovernmental Panel on Climate Change

KII: Key Informant Interviews

MSF: Médecins Sans Frontières

MSF-OCA: Médecins Sans Frontières-Operational Centre Amsterdam

NDVI: Normalized Difference Vegetation Index

NGO: Non-Governmental Organization

SAM: Severe Acute Malnutrition

SPICE: Setting, Perspective/Population, Intervention/Exposure, Comparison/Impact, Evaluation

UNICEF: United Nations International Children's Emergency Fund

WASH: Water, Sanitation, and Hygiene

WFP: World Food Programme

WHO: World Health Organization

WHZ: Weight-for-Height Z-score

Key Terms

Normalized Difference Vegetation Index (NDVI): an indicator of vegetation greenness, helping to evaluate vegetation density and monitor variations in plant health(1).

$PM_{2.5}$: Fine particulate matter is a form of air pollution made up of very small solid particles and liquid droplets that remain suspended in the air. Scientifically, it is defined by its size, specifically, particles with a diameter of 2.5 micrometers or smaller(2).

Weight-for-Height-Z-Score (WHZ): A key anthropometric measure utilized to evaluate the nutritional status of children is a statistical indicator that compares a child's weight to the median weight of healthy children of the same age, height, and sex (3).

Stunting: low height-for-age from chronic or recurrent undernutrition. It is linked to factors such as poor socioeconomic conditions, inadequate maternal health and nutrition, frequent illness, and/or improper feeding and care practices during infancy and early childhood(4).

Wasting: low weight-for-height, reflects recent and significant weight loss, often due to insufficient food intake and/or the impact of an infectious disease, such as diarrhea, which contributes to weight loss(4).

Extreme heat: is when forecasted heat indices exceed 41ºC during the day, coupled with nighttime temperatures of 27ºC or higher, expected to persist for two consecutive days(5).

Introduction:

“The Earth is not ours, it is a treasure we hold in trust for our children.”, African Proverb. Children are among the most vulnerable to the health impacts of climate change, yet they remain largely invisible in climate and health research. This is especially true in regions like the Sahel, where extreme climate events are increasing in frequency and severity, and health systems are fragile. Despite being our most precious resource, children, especially those under five, are often left out of climate-related planning and response efforts. There is an urgent need for more inclusive, age-sensitive, and context-aware public health strategies. Drawing on my experience working with vulnerable populations, this thesis seeks to explore the health consequences of extreme climate events on young children in the Sahel and to identify adaptive strategies that can inform more effective humanitarian and public health responses.

The Sahel region faces severe health inequities, high disease burden, and a skewed demographic profile: it is one of the youngest regions in the world, with children under five especially at risk. Yet, most climate and health research continues to overlook children, offering limited age-disaggregated data. This invisibility is concerning as extreme climate events, such as droughts, floods, and heatwaves, are intensifying in the Sahel, aggravating food insecurity, infectious diseases, displacement, and psychosocial distress, all of which severely affect young children. Médecins Sans Frontières – Operational Centre Amsterdam is seeking to better understand and respond to these emerging health risks. This research aims to support that effort by exploring how extreme climate events affect child health and development in this context, and by identifying actionable, adaptive strategies for humanitarian response.

Chapter 1: Background

Climate change refers to long-term shifts in climate patterns, such as changes in average temperature or weather variability, that can be measured over several decades using scientific methods, according to the Intergovernmental Panel on Climate Change (IPCC)(6). The IPCC has reported that human actions like the release of greenhouse gases from burning fossil fuels, cutting down forests, and altering land use are the main drivers of global warming we are seeing today(7). Since the industrial era, greenhouse gas concentrations have risen significantly, leading to an increase in average global temperatures by approximately 1.1°C compared to pre-industrial levels(7). This warming has also contributed to a sea-level rise of over 20 cm since the 1800s, due to melting ice sheets(8). Scientists have highlighted that climate change has also increased the frequency and severity of extreme climate events (ECEs), such as droughts, floods, heatwaves, and cyclones. These events are characterized by unusual and rare weather patterns that persist over some time(9).

Climate change impacts disproportionately affect populations in low-income countries despite their minimal contribution to greenhouse gas, and it has become one of the most pressing threats to global health equity(10). The Sahel is one such region, a wide, semi-arid strip of land that runs across Africa, just below the Sahara Desert, from Senegal in the west all the way to Sudan in the east (Figure 1). It acts as a buffer zone between the desert to the north and the greener, more humid savannah to the south(11). This region is especially vulnerable to climate change. Around 50 million people living in the Sahel are highly vulnerable to the effects of climate shocks because they rely heavily on traditional farming and raising animals to survive(12).

Figure 1: Sahel region of Africa (2025)(11)

The Sahel's vulnerability is exacerbated by its significant exposure to ECEs, making it one of the areas in Africa most affected by frequent and severe droughts(12,13). Projections indicate an

increasing frequency of extreme rainfall and flooding across the Sahel(14). Temperature increases in the Sahel are projected to be 1.5 times higher than the global average, with future rises potentially reaching 3 to 6°C by the end of the century. The region has already endured a series of droughts in 2005, 2008, 2010, and 2012, followed by floods in 2020 and 2021(14). The overall climate pattern is expected to become unpredictable, compromising both preparedness and disaster response efforts(14). Additionally, the region faces a general lack of funding for climate action, both from domestic and international sources, further complicating its ability to respond to these challenges(15).

Within the Sahel, some countries face particularly acute risks. Chad, Sudan, and northern Nigeria are some of the most climate-vulnerable globally: Chad, for example, is ranked by Notre Dame Global Adaptation Initiative as the most at-risk according to a global climate vulnerability assessment, due to the combined effects of poverty (87% of the population), conflict, and recurrent droughts and floods(16,17). Nigeria is listed by the World Bank as one of the ten countries most exposed to the consequences of climate change, with around 6% of its land area vulnerable to ECEs. These threats are especially severe in the northeast, where conflict and displacement intensify the health impacts of climate-related shocks by increasing vulnerability and limiting access to care(18). In Sudan, over 340,000 people were affected by floods in 2022, and the combination of climate shocks, conflict, and economic collapse has severely limited communities' ability to recover(19).

These overlapping crises contribute to alarming health outcomes, especially among children under five. Mortality rates in Nigeria, Chad, and Sudan stand at approximately 104, 101, and 50 deaths per 1,000 live births, respectively(20–22). In 2024–2025, Severe Acute Malnutrition (SAM) has affected 1 in 6 children under five in Chad, 1 in 8 in Sudan, and 1 in 17 in Nigeria(23–28). Children under five in Chad, Sudan, and northern Nigeria face a heavy burden of infectious diseases. Across the Sahel, water availability has decreased by more than 40% over the past 20 years, a decline attributed to both climate change and conflict-related disruptions. This increasing scarcity elevates the risk of waterborne diseases among children. More children die from unsafe water and sanitation in the Sahel than in any other region globally. In 2023, the region experienced its worst cholera outbreak in six years, with 5,610 cases and 170 deaths reported in Central Sahel(29). Diarrhea remains a leading cause of death in all three countries, accounting for 15% of child deaths in Chad, affecting 28% of under-fives in Sudan, and ranking second after malaria in Nigeria (with a national prevalence of 18.8%)(30–32). Malaria is endemic across the region: in Nigeria, it is the leading cause of death in under-fives, with studies reporting prevalence rates up to 52.9%; in Chad, nomadic children showed a malaria prevalence of 24.6%; and in Sudan, millions of children remain at high risk of epidemic diseases, including malaria(33–35). Acute respiratory infections (ARIs) also contribute to under-fives' mortality. Pneumonia causes 24% of child deaths in Chad, and ARIs account for nearly 20% of under-five deaths globally, with Nigeria's north disproportionately affected(32,35,36). These infectious diseases are increasingly exacerbated by the impacts of climate change, with children severely impacted due to their heightened vulnerabilities(37).

The broader global context reinforces these concerns. The World Health Organization (WHO) and the IPCC identify climate change as a major threat to global health(38,39). Its health impacts are diverse: climate change exacerbates existing health risks and creates new ones. These include elevated risks of heat-related illnesses, vector-borne diseases (malaria and dengue), waterborne infections, and diarrheal diseases (due to floods and poor sanitation)(38,39) . It also contributes

to mental health issues (stress, anxiety, depression, and trauma). Moreover, climate disruptions threaten food security and nutrition(38,39).

These impacts are especially harmful to children under five, who are more vulnerable to the consequences of ECEs due to their still-developing physiology, limited adaptive capacity, and dependence on adult caregivers(40). Young children are more susceptible to heatwaves, drought, and water scarcity, as well as flooding and the associated risks of cholera and vector-borne diseases, as they have not yet reached full physical and cognitive development(40). Several factors exacerbate the health impacts of climate change, including poverty, rapid population growth, displacement, unplanned urbanization, and weak governance(40). These challenges often limit governments' ability to meet the essential needs of their populations, especially children, and increase exposure to risks such as water contamination and inadequate sanitation in urban settings(40).

Consequently, climate-related threats such as malnutrition, waterborne diseases, malaria, and respiratory infections are emerging as major health challenges for under-fives across the Sahel(29). For example, in Chad and northern Nigeria, a combination of drought, conflict, and insecurity is driving severe water insecurity, placing 40 million children at extremely high risk due to a lack of access to safe and reliable water(29). Children under five bear nearly 90% of the disease burden from climate-related health risks(41). This is especially alarming, as the Sahel has the world's highest concentration of children under five(42). Their vulnerability is further heightened by widespread malnutrition, limited access to healthcare, and the increasing frequency of ECEs across the region(43). The World Bank has recognized that these ECEs pose a serious threat to children's health in the Sahel, contributing to under-five mortality through both direct (e.g., waterborne diseases) and indirect (e.g., food insecurity) pathways(44).

Recent events highlight these risks. In 2024, around 16 African countries, including Sudan and Nigeria, experienced unprecedented flooding, intensifying the spread of diarrhea(45). In Nigeria, recurrent flooding, especially in the northern regions, has led to widespread displacement and increased the risk of cholera outbreaks. In 2023, significant floods affected the majority of states, contributing to hundreds of cholera cases and dozens of deaths(45). Children under five were unevenly affected, representing a large share of confirmed cases. In northeast Nigeria, flooding has compromised access to food and clean water, exacerbating malnutrition and infectious diseases among children(45).

The indirect consequences of ECEs are equally devastating. In Sudan, flooding has worsened existing vulnerabilities by limiting access to essential medicines, while widespread hunger and malnutrition have left children susceptible to disease and mortality(45). Health teams report that many cholera-related child deaths are associated with complications coming from weakened immune systems due to malnutrition(45). The deterioration of the healthcare system is not only restricting emergency care but also interrupting critical routine services such as childhood immunizations. Months after the floods in Sudan, there has been a marked rise in preventable diseases, including cholera, measles, and dengue fever, contributing to hundreds of avoidable deaths(45).

These environmental challenges are worsened by other crises, including conflict, mass displacement, chronic food insecurity, and fragile health systems, making the Sahel a key intervention zone for medical humanitarian organizations such as Médecins Sans Frontières (MSF)(13). In the Sahel, where immense health needs are exacerbated by conflict and the increasing impact of climate change, Médecins Sans Frontières – Operational Centre Amsterdam

(MSF-OCA) has a significant operational footprint in Sudan, northern Nigeria, and Chad, responding to some of the most acute humanitarian crises in the region(46,47). Other MSF sections are also active in Sahelian countries, responding to critical humanitarian needs across the region(48,49), the overall context presents a major health challenge: according to a 2025 report, 29 million people across the Sahel require humanitarian medical assistance(50).

MSF-OCA's operations in Chad, Sudan, and northern Nigeria focus heavily on pediatric care, given the high burden of malnutrition, infectious diseases, and poor access to health services among children under five(46). In 2023, children under five represented 35% of all MSF-OCA outpatient and inpatient cases globally, and 47% of inpatients, highlighting the organization's pediatric focus. For instance, in Chad's Sila region, MSF's emergency response predominantly treated children often presenting with SAM, respiratory infections, and diarrheal diseases. Similar pediatric needs drive MSF's activities in Sudan and northern Nigeria, including nutritional support, treatment for Noma, and health care during displacement crises(46). Furthermore, MSF-OCA has identified climate and environmental health as growing medical priorities, with an increasing emphasis on adaptation, mitigation, and emergency action in response to climate-linked health impacts(46).

Chapter 2: Problem statement and justification

Despite increasing recognition of the broader health impacts of climate change, a significant gap persists in information and research specifically addressing the health impacts on children under five(51). This data deficit is critical, as current models fail to capture the acute health consequences of ECEs, such as floods and droughts, on child health outcomes like undernutrition, morbidity, and disrupted care practices(52). In the Sahel, where the increasing frequency and intensity of ECEs are creating such acute health problems for vulnerable populations, the demand for international humanitarian medical response is rapidly heightened. Yet, existing humanitarian efforts, including those by medical organizations, often struggle to effectively address the complex vulnerabilities and needs of children in these acute contexts, in crucial areas like routine healthcare and feeding practices(53). Furthermore, there is limited evidence of robust or effectively implemented child-centered emergency and health program adaptation(53), which is the modification of interventions to better address changing health needs and contexts, in response to ECEs among the most climate-vulnerable countries in the Sahel(54). Notably, only 2.4% of global climate financing is allocated to child-focused interventions, reflecting a broader neglect of children's needs in climate-related planning(15). These constraints reduce the capacity to manage risks and respond to disasters, weakening children's right to live in a safe and protective environment(15,40).

Emergency health organizations such as MSF are increasingly confronted with climate-related health crises in contexts where data is scarce and systems are fragile: MSF-OCA maintains a persistent operational presence in Chad, Sudan, and northern Nigeria(46). These nations are priority contexts for humanitarian medical action due to their deteriorating environmental conditions(16). All three countries rank among the most climate-vulnerable globally(16). Given these challenges, MSF-OCA actively responds to overlapping humanitarian, medical, and environmental crises, addressing the heavy burden of malnutrition, infectious diseases, and poor access to care faced by children in these settings, yet efforts are often restricted by a lack of context-specific evidence and data to guide effective interventions(16).

ECEs, such as floods, droughts, and extreme heat, create rapid, high-intensity health crises that affect young children(45). These acute health shocks overwhelm fragile health systems, making them a critical area of concern for humanitarian medical organizations such as MSF(19,46). Unlike long-term climate trends, ECEs demand immediate, life-saving interventions and emergency preparedness(45,46). There is growing interest in potential interventions to mitigate their health effects on children(53); however, there remains a gap in applying this evidence in vulnerable, operationally complex settings like the Sahel(13,45,53).

Although reports indicate a rise in ECEs across the Sahel, there remains limited evidence on their direct health effects, such as mortality and morbidity. This gap is largely due to a lack of observational data linking ECEs to specific health outcomes in the region(44). This is especially true for children under five. A recent United Nations International Children's Emergency Fund (UNICEF) report highlighted a critical gap in disaggregated, child-specific climate data, noting that the absence of localized, age-specific evidence destabilizes efforts to assess children's vulnerability and to design tailored protective measures and adaptation strategies(53).

To effectively mitigate the health impacts of ECEs on children in the Sahel, it is crucial to first establish the extent to which different ECEs affect child health outcomes across the Sahel. Building on this understanding, a comprehensive collection of information on existing effective interventions regarding ECEs and child health is essential. For these findings to be truly actionable and relevant for medical humanitarian organizations, it is imperative to integrate the invaluable perspectives of experienced health providers who have worked for years in the field. Such insights can critically inform medical humanitarian organizations in developing more targeted and context-appropriate strategies to mitigate the health impacts of climate-related emergencies on young children in this vulnerable region.

Chapter 3. Objectives

3.1) Purpose of the study:

To explore and identify the health impacts of ECEs on children under five years old, focusing on informing adaptive and emergency strategies to safeguard and enhance their well-being.

3.2) Research question:

How do ECEs affect the health of children under five in the Sahel, and what strategies can a medical humanitarian organization implement to respond to and reduce these impacts?

3.3) Specific objectives:

1. To assess how different ECEs affect health outcomes among children under five in Chad, Sudan, and northern Nigeria, by linking specific events to diseases.
2. To examine emergency response and program adaptation strategies targeting children under five during ECEs in the Sahel, focusing on Chad, Sudan, and northern Nigeria, with an emphasis on interventions applicable to medical humanitarian actors.
3. To explore the perspectives of the humanitarian field to validate, contextualize, and refine findings, and identify actionable strategies to mitigate the health burden of ECEs on children.
4. Provide actionable recommendations for medical humanitarian organizations to strengthen child-focused interventions and preparedness in the face of future ECEs.

Chapter 4. Methodology

4.1) Study design:

A literature review was conducted using a systematic approach and complemented by Key Informant Interviews (KIIs), analyzed according to the UNICEF climate change and child health framework, used to present the findings.

4.2) Analytical framework (UNICEF):

The UNICEF climate change and child health framework (Figure 2), based on child rights, environmental health, and climate change, was used(55). This framework highlights how climate-related hazards influence child vulnerability and climate-exacerbated multipliers, creating risks to child health, well-being, and survival, especially in low- and middle-income countries.

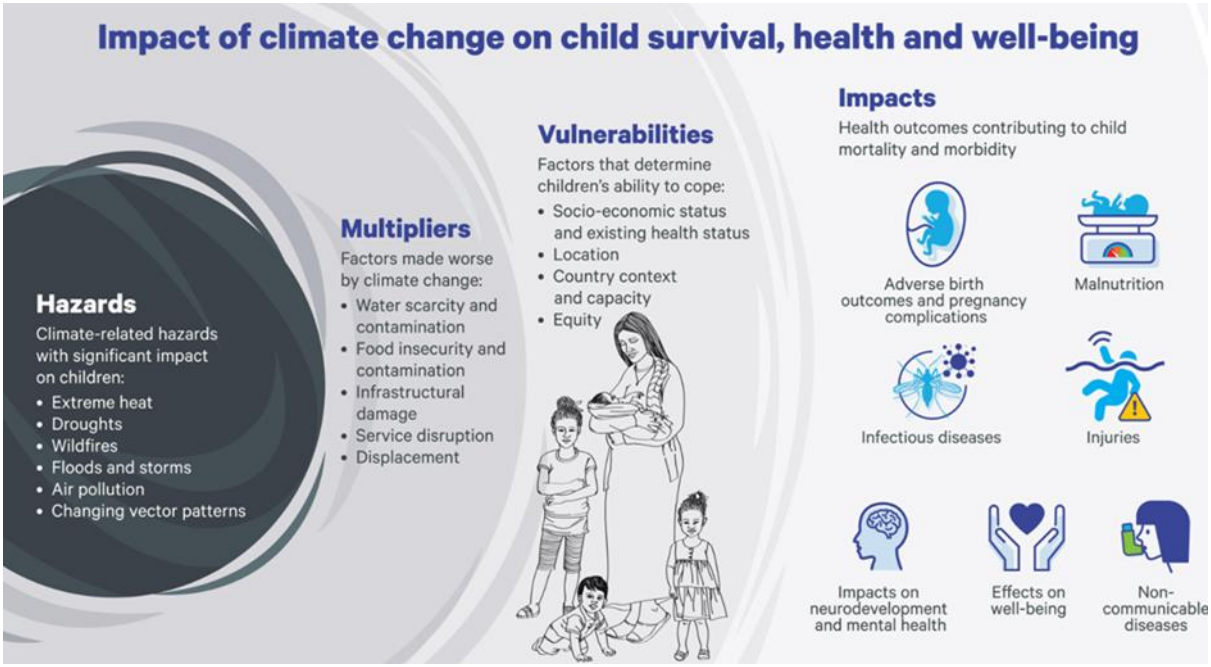

Figure 2: The UNICEF analytical framework(55)

This framework was selected for these reasons:

- Relevance to the population of interest: The UNICEF framework focuses on children under 18, with an emphasis on the under-five group, who are the most vulnerable to ECEs.
- Focus on ECEs: The framework categorizes climate hazards into heatwaves, droughts, floods, storms, and wildfires, events which are relevant to the Sahel.
- Humanitarian focus: The framework is grounded in UNICEF's operational experience and focuses on practical humanitarian concerns such as disease burden and malnutrition.

In conclusion, the framework aligns with the study's purpose: to identify health impacts of ECEs on children under five and explore adaptation strategies.

Refinements were made to the framework: "changing vector patterns" was reclassified from the list of climate hazards to health impacts, as it is not itself an ECE but rather a health-related consequence, closely associated with infectious disease patterns. Additionally, Normalized Difference Vegetation Index (NDVI) was introduced as a proxy indicator for drought, allowing for a more measurable representation of ECEs(56). While air pollution is not typically classified as an

ECE, it was retained in the framework due to its potential to result from wildfires. Furthermore, under the "impacts" category, the theme of “Health-seeking behavior” was introduced, acknowledging how ECEs can affect families’ access to healthcare(57). Moreover, to maintain a focus on concrete, measurable, and operationally relevant elements, the full complexity of vulnerabilities and multipliers outlined in the UNICEF framework was not explored in depth. The vulnerabilities identified in the framework are present in all contexts where humanitarian medical organizations like MSF operate and are often a reason for intervention. While multipliers are important for explanatory purposes, they primarily exacerbate the health impacts of climate change rather than trigger them. Therefore, they were not the primary focus of this literature review, although their influence is acknowledged where relevant in the findings.

4.3) Search Strategy and eligibility criteria:

The search strategy, eligibility criteria, and databases searched for objectives 1 and 2 are summarized below (Table 1):

Table 1: Search strategy and eligibility criteria of the literature review

	Objective 1 (Impacts of ECEs on children under five’s health)	**Objective 2 (Emergency response and program adaptation strategies targeting children under five during ECEs)**
Databases searched	PubMed, Scopus	PubMed, Google Scholar, MSF, Emergency Nutrition Network, UNICEF, International Federation of Red Cross and Red Crescent Societies (IFRC), WHO, Save the Children
Search strategy	Boolean search string based on ECEs, under-fives, health outcomes, and countries (see Annex 1), supplemented by snowballing Rayyan was used for screening	Boolean search string based on adaptation strategies, emergency responses, health impacts of ECEs, under-fives, countries (see annex 2), developed using the SPICE (Setting, Perspective/Population, Intervention/Exposure, Comparison/Impact, Evaluation) framework (see table 2), supplemented by snowballing
Last search date	31 May 2025	20 July 2025
Inclusion criteria	-Peer-reviewed Studies[1] examining the impacts of ECEs -Research in Chad, Nigeria, or Sudan specifically -Studies conducted in the Sahel, Sub-Saharan Africa, or Africa, only if they include at least one of the	-Studies or reports describing or evaluating adaptation or health emergency response strategies -Health interventions that target children under 5, or include them in the population studied, or studies focusing on lactating women, given their direct physiological and caregiving link to children under five.

	target countries in the data or analysis -Studies focusing exclusively on children under 5 or children in general, provided that those under 5 are included in the analysis -Studies published after January 2015[2] -Studies in English, French, or Arabic[3]	-Interventions implemented during or in response to ECEs -Research conducted in Sudan, Nigeria, and/or Chad, or studies focused on Sub-Saharan Africa or the Sahel region that include data or analysis from at least one of these three countries. -Interventions delivered by medical or humanitarian actors. -Studies, program evaluations, or literature reviews published after 2015 in English, French, or Arabic[2,3]. -Non-Governmental Organisation (NGO) or Humanitarian organization reports describing or evaluating real-world interventions or programs.
Exclusion criteria	-Policies, opinions of experts, guidelines, or position statements -Studies conducted in the Sahel, Sub-Saharan Africa, or Africa, that do not include Chad, Nigeria, or Sudan -Studies focusing only on other regions or countries outside the area of interest -Studies not focusing on children under 5 -Studies focusing on non-ECEs (slow onset or global changes) -Papers with predictions, not facts	-Studies not including any data or programmatic focus on Sudan, Nigeria, and/ or Chad (e.g., Global or non-African studies) -Studies that focus exclusively on adults or children over five without disaggregated data or clear inclusion of children under five or lactating women -Interventions not linked to ECEs (e.g., general development programs, or slow-onset climate changes) Theoretical, policy-only, or advocacy documents without description or analysis of actual interventions -All non-health-related programs, without a clear link to child health outcomes -Papers focused solely on the mitigation of emissions (carbon reduction) with no adaptation or health focus

[1]The selection was limited to peer-reviewed publications to ensure evidence comes from studies with robust methodologies and transparent reporting, which helps to minimize bias and supports the development of evidence-based insights.

[2]The literature review was limited to studies published from 2015 onward to ensure the inclusion of recent data and contemporary evidence relevant to current climate and health dynamics.

[3]Studies in English, French, and Arabic were included, as Arabic is the official language of Sudan, and both French and Arabic are official languages of Chad(58).

The SPICE framework (Table 2) structures literature search evaluation studies of the outcomes/impact of services, projects, or interventions, making it well-suited for health and

humanitarian research (59). In humanitarian contexts, it has been used to structure literature searches about the prioritization and effectiveness of aid interventions(60).

Table 2: Application of SPICE framework for Objective 2

SPICE element	Definition in this study
Settings (S)	Sahel region: mainly Chad, northern Nigeria, Sudan, countries where MSF-OCA works
Perspective (P)	Children under 5 years old, or studies where this group is explicitly included
Intervention/Exposure (I)	Health-related interventions implemented during or in response to ECEs, including humanitarian or medical responses
Comparison/Impact (C)	health outcomes among children under five, based on Objective 1
Evaluation (E)	Evaluating adaptation or emergency response strategies

4.4) Screening and study selection process:

The figures below illustrate the study selection process for assessing the health impacts of ECEs on children under five (objective 1) and for examining emergency response and adaptation strategies targeting this group (objective 2) during ECEs (Figures 3 and 4).

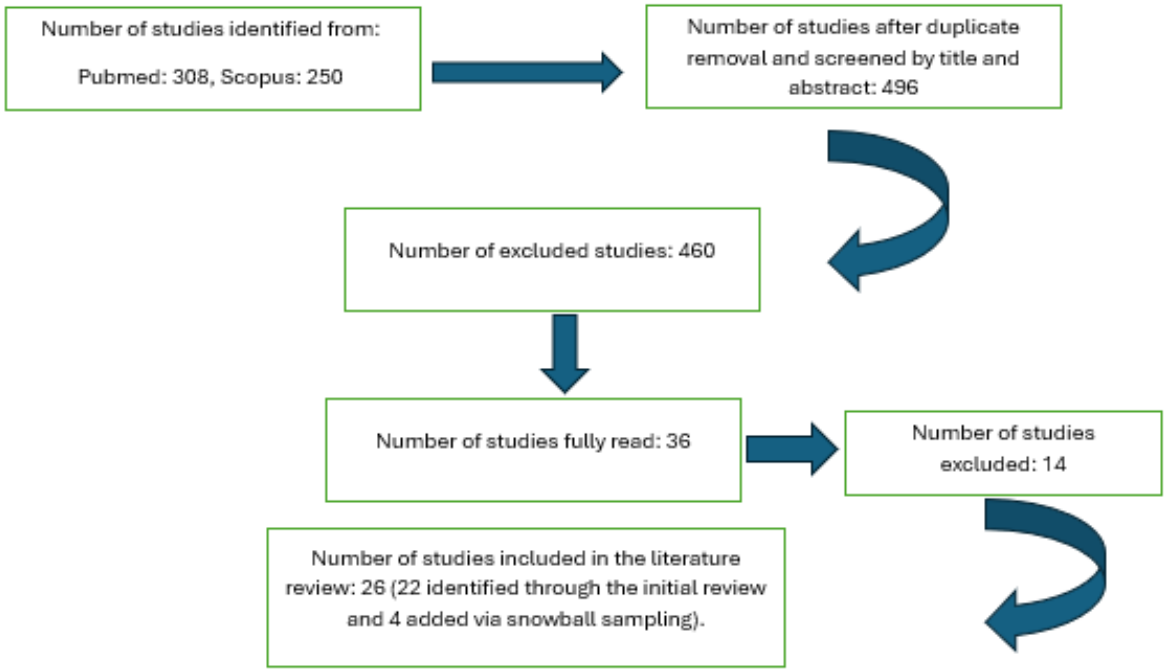

Figure 3: Study selection process to assess health impacts of ECEs on children under five (Objective 1)

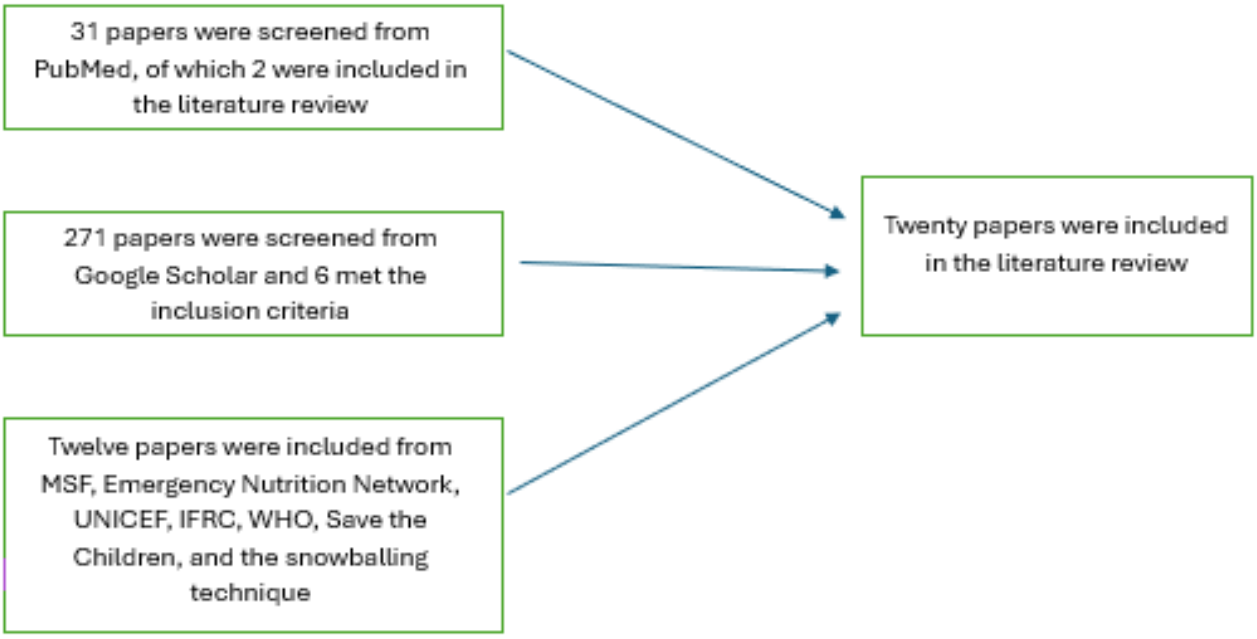

Figure 4: Study selection process to examine emergency response and adaptation strategies targeting children under five during ECEs (Objective 2)

4.5) Data extraction and synthesis:

To assess the impacts of ECEs on the health of children under five, the extracted findings were organized according to the ECEs outlined in the UNICEF framework(55). The reported health impacts were principally the health outcomes domains defined in the framework.

Also, emergency response and program adaptation strategies were categorized based on the specific ECEs described in the UNICEF framework.

4.6) KIIs:

KIIs were conducted to complement the literature review with context-specific perspectives by capturing the experiences and operational insights of humanitarian field workers. KIIs validate, enrich, and refine the findings. They also allow the identification of practical, actionable strategies that may not be well-documented in publications but are critical for improving real-world emergency responses targeting children under five during ECEs.

4.6.1) Participant Selection and Sampling

Participants were selected based on the following criteria: professional involvement with MSF or similar humanitarian organizations; expertise in children's health; experience with ECEs; knowledge of malnutrition and infectious diseases; and experience in one of the countries of interest. A combination of purposive and snowball sampling was used to identify suitable key informants from professional networks, including MSF staff and pediatric teams. Efforts were made to ensure diversity in geographic settings within the countries of interest, professional backgrounds (medical and non-medical), and organizational experiences beyond MSF, such as with other NGOs. This triangulation strategy was used to mitigate the risk of homogeneity in perspectives and enrich the insights gathered. The target was to conduct between four and six interviews.

4.6.2) Data Collection and Ethical Considerations

Semi-structured interviews were conducted in English using an interview guide (Annex 3). Ethical approval was granted by the MSF Ethics Review Board, with an approved waiver for the interview process from KIT. Before each interview, participants received information outlining the study's purpose and procedures before providing a written informed consent (Annex 4). Participants were informed that they could skip any question or withdraw from the interview at any time without consequence.

To ensure confidentiality and participant comfort, interviews took place in a private setting. All interviews were recorded and automatically transcribed, and then destroyed just after transcription. The transcripts were manually reviewed to ensure accuracy and to prepare them for analysis. Anonymity was maintained by replacing names with abstract identifiers and removing identifying details wherever possible. Interview data were securely stored on a password-protected personal drive, accessible only to the researcher. A summary of findings will be shared with participants who expressed interest, as a token of appreciation and transparency.

4.6.3) Thematic analysis:

KIIs were analyzed to explore the impacts of ECEs, corresponding emergency responses, and program adaptations. Analysis also addressed cross-cutting themes relevant across all types of ECEs.

Chapter 5. Results

5.1) Impacts of ECEs on children under five in northern Nigeria, Sudan, and Chad:

The following section examines how different ECEs affect health outcomes among children under five in Chad, Sudan, and northern Nigeria, organized by ECE type according to the UNICEF framework. The tables below (Table 2 and Table 3) summarize the distribution of studies included across countries and their classification by ECE type.

Table 3: Distribution of Studies by Country

Region	Number of studies
Nigeria	20
Chad	5
Sudan	2
Sahel	2

Table 4: Number of Studies by Extreme Climate Event Type

Extreme climate change event	Number of studies
Extreme heat	14
Drought (NDVI)	10 (including two of them used NDVI as a proxy for drought)
Extreme rainfall/floods	10
Wildfires	1

Details of the included studies, outlining their design, geographic focus, type of ECE, health outcomes assessed, and key findings can be found in Annex 5.

The following section presents the studies according to the climate-related hazard investigated, with a focus on:

5.1.1) Extreme heat:

Fourteen studies addressed extreme heat, reporting the following health impacts:

- Malnutrition
- Diarrhea (Shigella infection)
- Malaria
- Heat rashes

- Low birthweight and preterm birth
- Early childhood mortality

Studies across Nigeria and Chad show that extreme heat impacts children under five, increasing the risk of malnutrition and infectious diseases(61). A regional analysis confirmed that children are disproportionately impacted by extreme heat conditions(61). Multiple studies demonstrated that hotter temperatures are associated with higher rates of wasting in children(62,63,63–65). Marshak et al. reported a 5% increase in the odds of wasting, a 12% increase in wasting, and a 0.01 drop in Weight-for-Height Z-score (WHZ) in Chad, with seasonal peaks in wasting aligning with temperature trends(62). The authors noted that "these findings in Chad also appear in Sudan", supporting the idea that the effect of temperature on acute malnutrition may be generalizable across Sahelian contexts(62). In Nigeria, a maximum temperature of 38°C during the growing season was associated with a 25% wasting prevalence,10 percentage points higher than average(64). When the temperature rises by two standard deviations above average, waste risk increases by 8.1%. Interestingly, maternal education, gender, and household crowding did not moderate the effect of extreme heat on wasting, though rural and urban differences were observed: rural children benefited less from cooler temperatures, but during heatwaves, both urban and rural children experienced similar increases in risk(65). A Nigerian study and a book chapter further confirmed that extreme heat and more frequent heatwaves elevate the risk of stunting and underweight in children under five(66,67).

Extreme heat was also shown to raise the risk of diarrhea in children. Studies found that a 1 standard deviation rise in temperature led to a 1.6 percentage point increase in diarrhea prevalence(63). This effect was immediate and more pronounced in rural areas, where poor water and sanitation infrastructure made children more vulnerable(63). The study also found that protective factors such as breastfeeding and flush toilets could mitigate the risk(63). Similarly, each 1°C increase in temperature raised diarrhea cases by 6.7% in both Nigeria and Chad(68). Conversely, Dunn et al. found that lower temperatures were protective against diarrhea in Nigeria, due to reduced fly activity and slower pathogen proliferation(14). In terms of Shigella infection, A global study observed that extreme heat was associated with a decrease in infection risk in Nigeria, which contrasts with the assumption that heat raises enteric disease risks(69).

For all-cause child mortality, hotter days were paradoxically associated with lower mortality rates in Nigerian children aged 1 month to 5 years: post-neonatal and early childhood deaths decreased by 6% and 8% respectively, during hot periods, though the confidence intervals suggest some uncertainty(70).

The relationship between temperature and malaria appeared complex. A 2020 study found that malaria prevalence in Nigerian children rose with moderate temperature increases but declined during heatwaves(71). This suggests that extreme heat may disrupt mosquito development or shorten transmission windows. Regional variation was significant, with higher malaria clustering in northern states(71).

Moreover, heat rashes and other stress-related conditions have been reported across Nigeria, with children under five being among the most vulnerable groups affected(61).

Heat exposure during pregnancy has also been linked to adverse birth outcomes. A study that included Nigeria found that third-trimester exposure to heatwaves reduced birthweight by an average of 41.8 grams and increased the proportion of low birthweight infants(72). Maternal stress, undernutrition, and disease burden were potential pathways(72). Moreover, very hot

temperatures shortly before delivery increased the risk of preterm birth, highlighting how the timing of exposure matters(73).

5.1.2) Drought and/ or low NDVI:

Ten studies addressed drought (NDVI), reporting the following health impacts:

- Malnutrition
- Fever/cough
- Diarrhea
- Malaria

In the Sahel, with a concentration of evidence from Nigeria, across the studies reviewed, droughts are associated with increased under-five child undernutrition.

In Nigeria, reduced vegetation and rainfall elevate the risk of acute malnutrition in children under five. For example, a spatial and hierarchical analysis found that a one-unit increase in NDVI (more vegetation) was associated with a 9.2% decrease in the probability of child wasting, suggesting that greener environments, indicating better agricultural and environmental conditions, offer a protective effect(64). Similarly, more vegetation and rainfall were linked to lower levels of underweight among children. The findings highlight how droughts affect child malnutrition(74).

Extremely declining precipitation increases both stunting and underweight in Nigeria(66). And extreme decreases in rainfall led to a 35.6% decline in WHZ, although this did not translate into a significant increase in wasting(66). Interestingly, maternal education, gender, and household crowding did not modify this relationship, indicating that drought-related nutritional vulnerability may affect children under five regardless of these factors(65).

For further depth, drought severity is associated with lower WHZ scores among Nigerian children(75) The analysis highlighted that northern and northeastern Nigeria, where severe drought is most common, experience the highest levels of wasting(75). Moreover, during droughts, the typical nutritional advantage due to breastfeeding observed among younger children diminishes. One plausible mechanism is that breastfeeding mothers may suffer from food insecurity and physiological stress, reducing breastmilk(75).

In Sudan and across the broader Sahel, data suggest that drought has had complex impacts on child health. In 2017, it was documented how major drought cycles in Sudan during the 1970s and 1980s led to a decline in malaria transmission, but more recent trends toward wetter conditions have reversed this, increasing the suitability for malaria vectors and possibly raising under-five child malaria morbidity again(76).

Meanwhile, researchers found that elevated childhood diarrhea rates in northern Nigeria during 2011–2013 may have been linked to drought(77). Anomalously dry conditions were also associated with an increased risk of fever among children under five in Chad, Nigeria, and Sudan(78). Interestingly, in Nigeria and Chad, precipitation anomalies, including drought, were associated with mixed health outcomes. In dry zones, no significant link was found between drought and fever, diarrhea, or cough, while in tropical savannas, anomalies showed a protective effect on fever(78).

Reviews note that drought increases malnutrition by indirectly contributing to the under-five child health vulnerabilities. For instance, male out-migration during droughts places greater caregiving burdens on women, which may compromise infant care and nutrition(67,79).

5.1.3) Floods:

Ten studies addressed floods (extreme rainfall), reporting the following health impacts:

- Malnutrition
- fever
- Diarrhea (Cholera, Shigella infection)
- Malaria
- ARIs
- Altered health-seeking behavior

In Nigeria, floods have been linked to increased risks of malnutrition. A recent study found that flooding was associated with higher rates of stunting among children(64). Also, a case evidence in 2025 reported a dramatic surge in cases of wasting, up to 160%, following flooding(18). The 2023 and 2024 floods disrupted food systems and agricultural livelihoods and also coincided with a rise in malnutrition-related complications among children. These findings emphasize how flooding worsens food security, amplifying nutritional vulnerabilities already strained by conflict and displacement(18).

Wasting was also associated with excessive rainfall in Nigeria(65). Interestingly, common protective factors such as maternal education did not alter the risk, nor did household crowding or gender, suggesting that Floods can weaken the usual protections that help children under five stay healthy(18).

Regarding infectious diseases, a recurring theme in the literature is the elevated burden of diarrhea following floods. A sub-Saharan study demonstrated a significant 0.6% increase in diarrhea cases per millimeter of extreme rainfall in both Nigeria and Chad(68). This link is mediated by fragile Water, Sanitation, and Hygiene (WASH) (68). When open defecation is common and many households rely on basic toilets or get unsafe water, floodwaters transport fecal matter into boreholes, intensifying the risk of waterborne diseases(68).

Cholera outbreaks in Nigeria often follow floods. Denue et al. reported an outbreak in Borno State during flooding, and Ogburia et al.noted that floods contributed to active cholera transmission in 32 states, with children under five especially vulnerable. These outbreaks occur in areas with poor drainage, damaged sanitation, and limited clean water, conditions worsened by flood-related displacement and overcrowded shelters(80,81)

Floods also exacerbate ARIs. An analysis in 2023 found an association between extreme rainfall and ARIs in Nigeria (OR 2.14, 95% CI 1.06–4.31), due to increased exposure to moist environments, airborne pathogens, and indoor crowding during flood-related evacuations, like during the 2018 floods(82).

Regarding malaria, in northern Nigeria, a study about children's malaria reported that malaria prevalence increased during floods(71). Flooding may contribute to the formation of mosquito breeding grounds(71). In contrast, in Sudan, while flood duration was significantly and negatively

correlated with malaria incidence among children under five (ρ = -0.396, p = 0.033), flood frequency had no significant impact. The authors proposed that longer floods may wash away mosquito larvae and breeding sites(83).

In some settings, floods increase malaria risks, while in others, they act as temporary suppressants. The complexity deepens when multiple ECEs overlap. The Sudan study points out that droughts and storms co-occur with floods, disrupting disease trends in unpredictable ways(83). In Chad and Nigeria, floodings were associated with a reduced odds of reported fever (pooled OR 0.75)(78). For Shigella, a study reported an increased risk following extreme rainfall, but only when soils were moist from prior precipitation(69).

Image 1: Flooding in Northeast Nigeria in 2024*(84)*

5.1.4) Wildfires and air pollution as a consequence:

One study addressed wildfire, reporting the following health impact:

- Child mortality

Xue et al. examined the associations between wildfires and child mortality across low- and middle-income countries, and both Nigeria and Chad were included among the analyzed settings. In Chad, exposure to fire-sourced $PM_{2·5}$ concentrations reached levels around or above 30 μg/m^3. This high exposure was associated with an increase in under-five mortality, as indicated by hazard ratios exceeding 1. The overall result demonstrated a concerning link between wildfires and child deaths under five. In Nigeria, the fire-related $PM_{2·5}$ concentration was lower, approximately 15 μg/m^3. The risk of mortality in Nigerian children under five was also elevated, with a hazard above 1, though the association appeared less pronounced than in Chad(85). Although significant, the wide range of hazard ratios suggests statistical uncertainty, limiting the precision of these findings(85).

5.1.5) No data has been found on the impacts of storms on children under five's health in Chad, Sudan, or northern Nigeria

5.2) Emergency response and program adaptation strategies targeting children under five during ECEs in the Sahel

This section reviews emergency response and adaptation strategies for children under five during ECEs in Chad, Sudan and northern Nigeria, with findings organized by type of ECE (see Table 5 for a summary)

Table 5: Emergency Response and Adaptation Strategies for Children Under Five During ECEs

ECEs	Health Intervention Area	Intervention(s)
Extreme Heat	Infectious Diseases	Early warning systems (malaria and meningitis), vaccination campaigns (meningitis)(86)
	WASH / Dehydration	Distribution of clean drinking water in displacement shelters(87)
	Environmental Health	Tree planting to increase shade(88)
	Health Education	Climate-smart education (Promoting hydration, suitable clothing, cool activity schedules, and ventilation)(89)
Drought	Malnutrition	Community-based supplementary feeding programmes and SAM treatment(85–87)
	Health Access	Mobile clinics to maintain care in remote areas(93)
	Vaccination	Measles vaccination campaign(91)
	WASH / Health Education	Hygiene education and WASH integration(90,94)
	Preparedness / Early Action	Anticipatory action: Child-centered drought/disease protocols activated(94)
Floods	Vaccination	Measles and pneumonia vaccination campaigns (95,96)
	Infectious Disease	Cholera and malaria treatment centers (84,94,96,97)
	Malnutrition	Supplementary feeding, mobile consultations, SAM treatment (84,90,95,97,98)
	Mental Health / Child Protection	Psychosocial support, child-friendly spaces, safeguarding(84,95,99)
	Health System Strengthening	Solarized health facilities, strengthening cold chains, and trained health workers in integrated child health(96)
	Vector control	Bed net distribution(84,96)
	WASH	WASH kit distribution, water chlorination, rehabilitation of infrastructure(95,98–100)
	Preparedness / Early Action	Early warning, pre-positioning of supplies, digital flood monitoring(94,99,101,102)
	Maternal and Newborn Health	Maternal kits, newborn services, midwifery training (96,99)
	Nutrition Screening / Referral	Mid-Upper Arm Circumference screening and referral by mothers' clubs(90)
Wildfires	Environmental Exposure	Recommendation to discourage children's outdoor activities(89)
ECEs (General)	Malnutrition	food assistance and fortified foods(103)

5.2.1) Extreme heat:

Four papers addressed extreme heat.

In the Sahel, efforts to mitigate health risks linked to extreme heat have focused especially on diseases with strong seasonal patterns that are worsened by high temperatures. A study on early warning climate indices for malaria and meningitis(86) highlighted preventive strategies, including the development of an early warning system to anticipate outbreaks of both diseases and the launch of a meningitis vaccination campaign targeting children under five. These interventions aimed to reduce the burden of malaria and meningitis during periods of elevated risk. In Sudan, emergency measures included the distribution of clean drinking water in displacement shelters, where temperatures reach 41 °C, to prevent dehydration and heat strokes among young children(87). In Nigeria, children in informal settlements proposed tree planting to increase shade(88), while public health experts advocated for climate-smart education, encouraging hydration, appropriate clothing, scheduling outdoor activity during cooler hours, and ensuring well-ventilated spaces for accommodation and learning(89).

5.2.2) Droughts:

Five papers addressed drought.

In northern Nigeria, droughts worsened by conflict and economic instability have led to a hunger crisis. In response, the Nigerian Red Cross implemented feeding programmes for children with acute malnutrition(90). Community-based approaches were key to the response, with volunteers trained in managing acute malnutrition and infant feeding. Simultaneously, mothers' clubs were set up in drought-affected states to conduct house-to-house sensitization and support referrals through meetings. These clubs became platforms for nutrition screening, hygiene education, and WASH activities, contributing to a broader health systems approach(90). Together, these interventions improved early intervention, strengthened community capacity, and helped prevent the worsening of malnutrition among children under five(90).

In Sudan, a historic four-year drought compounded by flooding in 2023 deepened an existing health crisis across the Greater Horn of Africa. According to WHO, one million children with SAM were admitted to therapeutic feeding programmes across emergency settings, in the Greater Horn, as reported by implementing partners(91). In Sudan, children received treatment for SAM in stabilization centers(91). Simultaneously, WHO strengthened technical capacity within the health system by adding more nutrition experts to its team and training trainers in hospital-based management of SAM. During the same period, 25 million children under five, including Sudanese children, were vaccinated for measles, an intervention crucial for reducing disease vulnerabilities during drought-nutrition crises(91).

Further health system strengthening measures in Sudan addressed the nutrition of children aged 6–23 months in food-insecure areas(92). Supplementary food and micronutrient powders were distributed through both the health and food systems(92). Primary health centres and community-based platforms like mother and father support groups facilitated behavioural change interventions, improving complementary feeding practices among caregivers(92).

In Chad, the 2012 Sahel drought had a severe impact on remote regions. A project led by the national NGO "Bureau d'Appui Santé et Environnement" and supported by UNICEF and the World Food Programme (WFP) deployed mobile clinics to overcome access barriers to fixed health facilities(93). This strategy allowed humanitarian actors to provide treatment for acute

malnutrition during the lean season, when rates of undernutrition rise. The stability of admission rates during the lean season suggests that mobile outreach services were successful in maintaining care continuity and supporting affected populations. These findings showed the importance of mobile health delivery as a means of ensuring service access in hard-to-reach areas during drought emergencies (93).

In 2024, anticipatory action became a key component of drought-related response in Sudan. Save the Children activated community-based, multi-hazard, and child-centred early action protocols for drought and disease outbreaks in seven states. Developed in collaboration with communities and national authorities, these protocols guided specific interventions(94). During cholera outbreaks, actions included child-centered risk and prevention communication, waste disposal, and distribution of mosquito nets(94). These anticipatory efforts represent a shift towards early, community-embedded preparedness in the face of frequent and severe droughts(94).

5.2.3) Floods:

Thirteen papers addressed floods.

UNICEF in Chad reached children with measles vaccination in response to the 2024 floods(95). To combat vector-borne diseases like malaria, the distribution of mosquito nets is a prevalent and effective intervention. UNICEF and partners in Sudan distributed mosquito nets and supported other prevention and management measures, providing children under five in high-risk states with Long-Lasting Insecticidal Nets to protect them from malaria(96). In Nigeria, fears of outbreaks of malaria and acute watery diarrhea increased post-flooding, with observed clinical signs of cholera needing increased medical support and WASH interventions(84). In Chad, the lack of potable water after floods was noted to compromise child nutrition, leading to efforts to strengthen WASH infrastructure(99). UNICEF distributed household WASH kits, prioritizing families with breastfeeding women and children under five, addressing the heightened risk of waterborne diseases(95). In Nigeria, UNICEF supported state governments in reinforcing emergency coordination for WASH, which included chlorinating water and distributing WASH dignity kits(98). In Sudan, flooding damaged WASH systems, displaced populations, and contaminated homes, heightening cholera risks. Save the Children's WASH programming focused on ensuring access to clean water, sanitation facilities, and hygiene promotion, including water quality monitoring, environmental hygiene, rehabilitation of WASH facilities, solid waste management, and capacity building(100). Flood-triggered prevention actions in Nigeria included risk communication and early warning(94). In the context of cholera prevention, multi-hazard protocols in Sudan encompassed waste disposal and distribution of mosquito nets(94). To ensure continuity of care in flood-affected and inaccessible areas, mobile and outreach health services are crucial. UNICEF in Sudan contributed to these efforts by supporting the provision of mobile and outreach health services for children under five(96). In Nigeria, UNICEF supported the Ministries of Health and the State Emergency Management Agency to reach inaccessible populations with Maternal, Newborn, and Child Health services through mobile brigade services(98). MSF in north Nigeria conducted outpatient medical and mental health consultations in displacement and flood-affected areas, supplied water via trucks, rehabilitated boreholes and latrines to address WASH needs among displaced families with children under five, planned to expand paediatric facilities by 100 beds to meet the anticipated demand for malaria cases, and established a cholera treatment center with a potential 100-bed capacity(84,97).

Floods have worsened malnutrition among children under five by disrupting food security. In Nigeria, humanitarian responses included Red Cross supplementary feeding and malnutrition screening(90), International Committee of the Red Cross (ICRC) support for additional health

centres offering treatment for complicated cases(104), and UNICEF's outpatient therapeutic care with micronutrient supplementation(98). In Chad, UNICEF treated children with SAM(95). In Northeast Nigeria, MSF teams were running medical consultations via a mobile clinic in the Yerwa camp, addressing one of the worst malnutrition crises recorded in the region(84). Beyond direct treatment, efforts were directed at promoting healthy feeding practices for mothers and children. In Nigeria, mothers' clubs were established across seven states, conducting house-to-house visits to sensitize mothers, fathers, and caregivers on mother and child nutrition, maternal and child health, and hygiene promotion(90). These clubs also served as a platform for babies' mid-upper arm Circumference screening and referral(90). The IFRC in Chad intended to distribute 500 maternal kits to breastfeeding women. This initiative aimed to enhance maternal and child hygiene, encourage breastfeeding, and increase engagement with health centers(99). During the 2013 flooding in Sudan, disaster relief efforts also included support for breastfeeding or nutrition, with milk powder being provided by "Hajar company" and the Humanitarian Aid Commission, which was interpreted as being for infants, although data on how many lactating mothers or infants received help was not found(101).

The displacement and psychological impact of floods necessitate interventions focused on child protection and mental health. Creating safe environments and providing emotional support are crucial. In Chad, UNICEF established a child-friendly space to provide a secure environment where children affected by the 2024 floods could engage in play and access essential comfort(95). UNICEF also provided mental health and psychosocial services to children and caregivers(95). In the context of the 2024 floods in Chad, ensuring the safety of children from various forms of violence was a priority(99). The IFRC developed plans to train its volunteers on adherence to child protection policies. Concurrently, the organization intended to map existing local referral systems and disseminate information regarding these systems to address any child protection concerns(99). A post-emergency phase also included a child safeguarding risk analysis and the task of sensitizing communities regarding violence against children(99).

Beyond immediate response, interventions also focused on strengthening healthcare infrastructure and disease-specific prevention(96). This involved supporting the functionality of health facilities to deliver integrated services and conducting extensive immunization campaigns against pneumonia and measles. The robustness of vaccine delivery was further enhanced through the reinforcement of the cold chain system(96). Efforts also included capacity building for health workers in the integrated management of childhood illnesses and essential midwifery services, strengthening primary healthcare(96). Furthermore, infection prevention and control measures were implemented. This approach was illustrated by the solarization initiative in Sudan, which equipped rural health facilities and immunization services, especially those targeting children under five(96).

Proactive actions informed by climate forecasts can reduce the effects of flooding. In Nigeria, focal points in field offices, local partners, and Disaster Risk Reduction or Early Warning and Anticipatory Action committees use an app to monitor the impacts of floods and conflicts(102). This locally gathered data is then integrated with national hydrological and forecasting information to issue alerts and support anticipatory measures at the community level(102). Community-based Anticipatory Action initiatives in Nigeria have also aimed to localize weather and climate information by combining local knowledge with scientific monitoring and forecasting(102). These anticipatory actions can also trigger child-centered early action protocols for floods, where the analysis of stagnant water conditions and rainfall forecasts specifically activate a cholera response tailored for children under five, with the distribution of mosquito nets to combat malaria(94). To ensure a quick response, essential supplies were pre-positioned in anticipation of emergencies. In Nigeria, efforts were undertaken to improve the efficiency of

procuring Ready-to-Use Therapeutic Food and to establish pre-positioned nutritional supplies, ensuring nutritional support for children under five in flood-affected areas(98).

Image 2: A child-friendly space in Chad, established after the 2024 flooding*(95)*

5.2.4) Wildfires:

One paper addressed wildfires.

Nigeria Health Watch, in collaboration with experts, recommends discouraging outdoor activities for children during poor air quality from wildfires or heavy smoke to protect their health during climate extremes(89).

5.2.5) ECEs in general:

One paper addressed ECEs in general.

In Nigeria, the WFP implemented a strategy aimed at enhancing the capacity of local institutions and communities to respond to climate-related shocks. In the northern regions, particular attention is given to improving the nutritional status and food security of children, with interventions adapted to the specific needs and challenges of each locality. Since initiating operations in 2016, the WFP has provided emergency food assistance to children most affected by ECEs and severe food insecurity. Notably, in-kind food distributions (Specialized Nutritious Foods like Fortified Cereals and Ready-to-Use Therapeutic Foods) have reached infants aged 6 to 9 months, contributing to short-term nutritional relief and long-term resilience(103).

5.2.6) Storms: No findings about emergency response and program adaptation strategies/

5.3) The field perspective:

Four of nine key informants were interviewed; the others were unavailable due to travel. The respondents included a Medical Coordinator (MedCo), program manager, emergency health manager, and field health worker, with experience in MSF, IFRC, UNICEF, and Action Against Hunger.

5.3.1) Extreme Heat

- Impacts:

Participants across the interviews consistently described extreme heat as a worsening crisis, noting its increasing frequency and intensifying health consequences. The daily struggle for survival that extreme heat presents was highlighted.

"Just thinking, being in the shade... it's a battle daily.", Key informant 1, Emergency health manager.

Participants noted that extreme heat severely impacted children's health, leading to dehydration, heat stress, and complications during birth. One practitioner confirmed the theoretical link between heat and birth complications, but emphasized the more pressing systemic concern: heat's disruption of care delivery itself.

"We know in theory that things like preterm labor, low birth weight babies... have a link to extreme heat.", Key informant 2, field health worker.

Extreme heat forced clinics to close early because patients and staff were collapsing. This created an impossible situation for vulnerable families, especially those who were displaced and lacked any form of shelter.

"Patients and nurses were collapsing from the heat.", Key informant 2.

"Living in a desert on the sand with no shelter."Key informant 3, MedCo

Extreme heat was found to visibly reduce the capacity of caregivers, who were often too exhausted to perform essential tasks. One respondent described how this exhaustion affected the quality of care children received.

"Less time to cook, less time to take care of them, less time to feed them... all those caring tasks are affected.", Key informant 4, program manager.

Another participant provided a stark example, highlighting the life-threatening conditions for newborns and their mothers in temporary shelters.

"Children are being born in tents at 43 degrees. The babies are too hot, the mothers are exhausted.", Key informant 1.

- Emergency response and program adaptation strategies :

While direct strategies were still in development, respondents voiced growing concern about the need to prepare for heat-related operational challenges. Staff in Sudan, for example, struggled to provide healthcare in extreme heat, often relying on basic resources.

"When you are sitting in a little hut, you might be in shade, but you know, it's still super hot.", Key informant 2.

Respondents suggested adjusting clinic hours to avoid the hottest parts of the day, a practice that was incidental but is now being discussed more formally to protect both patients and staff.

"Clinic hours had to be adjusted to avoid the peak of the heat.", Key informant 1.

There was a strong emphasis on infrastructural needs, such as creating shaded waiting areas, improving ventilation, and installing solar-powered cooling in clinics, particularly in neonatal units.

"We also have to be realistic... but at least securing the hospital places to make sure that care can be given to the most vulnerable ones.", Key informant 3.

Finally, there was a consensus on the need for increased community outreach, especially during heatwaves, as long walks to clinics endangered both children and caregivers. However, this outreach was often limited by a lack of resources and security concerns.

"There was agreement on the need to 'get close to the community.'", Key informant 4.

5.3.2) Droughts

- Impacts:

Respondents consistently framed drought as a prolonged and structural crisis with cascading effects on child survival. Practitioners described how environmental degradation has damaged agriculture and self-reliance, with some areas becoming consumed by sand.

"It was kind of scary... some villages were being covered by sand.", Key informant 3.

"People can't cultivate anymore.", Key informant 4.

The scarcity of water has become a dominant challenge, with people having to walk very long distances to find it. The immense physical toll of this journey was highlighted by a respondent who noted that even camels were dying and that walks that once took two hours now take four, making some areas uninhabitable.

"People have to walk very long to find water... even camels are dying.", Key informant 1.

"It's not a two-hour walk anymore, it's four. These areas will become uninhabitable.", Key informant 2.

This water scarcity is aggravated by contamination in shared water basins, leading to outbreaks of infectious diseases. "Hundreds of people were lying under trees dying of cholera.", Key Informant 3.

The worsening effects of drought, including hunger, diarrhea, fatigue, and poor hygiene, were described as overwhelming. In some cases, there wasn't even enough water for safe childbirth, severely limiting the ability of practitioners to provide care.

"If you have not enough water available, then we reach our limits in how to provide care.", Key informant 1.

Moreover, with men migrating for work, the caregiving burden on women with young children has intensified.

"Women with children under five carry the full weight when men migrate for work.", Key informant 2.

- Emergency response and program adaptation strategies :

According to the respondents, program adaptation to droughts is currently limited and needs to be extended urgently, with water access being the most immediate need.

"The scarcity of water is something that we have to find a way to address... we might dig more wells or stuff like that.", Key informant 4.

Some organizations have collaborated to support household resilience by providing drought-resistant seeds or food aid. A respondent highlighted that this kind of intervention is possible and valuable, even if medical actors are not leading these efforts directly.

"You will give seeds that are more resistant to drought... this kind of things can be done.", Key informant 3.

Despite these efforts, most respondents expressed the limits of their current capacity, noting that the demands of climate-exacerbated droughts often exceed what humanitarian teams can provide.

"You can do little things at the moment.", Key informant 1.

5.3.3) Floods

- Impacts:

Floods were described as increasingly frequent and destructive events with devastating health consequences. One respondent recalled the severity of these events, noting that entire health facilities could be submerged, disrupting care access for weeks.

“Entire clinics were submerged in the last floods in Chad.”, Key informant 1

The destruction of housing and crops was a common outcome, which destabilized families and led to food insecurity. The floods also contaminated water systems by creating stagnant water where sewage and freshwater supplies were no longer separated, leading to a host of health issues.

“Floods destroy the harvest, so you won’t have access to food... they destabilize the whole life of a family.”, Key informant 3.

As a result, children developed diarrhea, skin infections, and malaria. They were often unable to reach care, with some going unseen by health providers for more than a week because their families were stuck in flooded areas.

“Some not seen (by health care providers-ed) for over a week because their families couldn’t leave the flooded area.”, Key informant 2.

Access to healthcare was repeatedly interrupted by the collapse of infrastructure, as roads and bridges were washed out. This meant that ambulances could not pass, and entire communities were cut off from health services for weeks.

“We saw areas cut off from health access for weeks due to floods; ambulances couldn’t pass.”, Key informant 3.

For severe cases, such as neonatal complications, access was critically inadequate, as a simple mobile clinic was insufficient for the level of care required.

“If someone needs oxygen and inpatient care, a mobile clinic is not enough.”, Key informant 1

Even the mobile clinics themselves often became unreliable, either due to a lack of predictability or insufficient services. These logistical failures placed children under five at heightened risk of untreated dehydration, infections, or severe malnutrition.

“Mobile clinics are not always reliable if people don’t know when we’re coming or what we can offer.”, Key informant 4.

- Health adaptation and emergency response strategies

There was strong support for anticipatory action to prepare for floods, with respondents noting that despite communities knowing where to evacuate, organizations often failed to set up pre-designated sites. This demonstrated a critical gap in preparedness.

“We had flooding in the same place two years in a row… the community knew where they would evacuate, but we didn’t set up a pre-place.”, Key informant 4.

A key strength, however, was the rapid response from communities themselves. Local volunteers were often the first to act, organizing essential services like water points before external teams could even be deployed.

“Sometimes it’s the community volunteers who react first. They organized water points before we could even deploy.”, Key informant 2.

Respondents repeatedly emphasized the need to prioritize water treatment and access strategies. While some protections exist, greater emphasis should be placed on ensuring water is safe for consumption.

“There’s some protection for rain and stuff like that, but I think we should emphasize water treatment more.”, Key informant 3.

In some cases, health teams considered using boats to navigate flooded areas so that critical services, like emergency referrals, could continue. However, scaling these adaptations to meet the demands of intensifying floods remains a significant challenge.

“We look into boats or other ways to manage water so that emergency referrals can still happen.”, Key informant 1.

5.3.4) Wildfires and storms:
None of the interviewees provided insights on wildfires or storms.

5.3.5) Cross-Cutting Themes in Health Impacts and Responses:

- Maternal Caregiving Trade-offs and Gendered Burdens:

ECEs deepened the strain on mothers juggling multiple responsibilities.

“The mother has to choose: stay with the sick one or go home to feed the other six. It’s an impossible decision, but she makes it every day.”, Key informant 3.

- Neglect of Children with Disabilities and Overlooked Groups:

Disability inclusion was missing across interventions.

“disabled kids in these settings are invisible.”, Key informant 2.

- Mental Health Gaps for Children and Caregivers:

Despite trauma, fear, and loss, mental health remained unaddressed.

“There’s trauma, fear, instability, but no trained staff to help children process it. Caregivers requested child-friendly spaces and structured play.”, Key informant 3

- Community-Led Responses and Local Adaptation:

Local actors were often the first to act. “Sometimes, the community responds faster than we do. They know the land, the risks, the escape routes, but these efforts were rarely integrated or resourced.”, Key informant 3

- Conflict and Climate worsening Crises:

Especially in Sudan, the conflict complicated the climate response. “There’s absolutely nothing happening to children in Darfur that is about climate only.”, Key informant 1.

- Lack of Preparedness and Anticipatory Action:

Despite known risks, planning remained reactive. “We’re always surprised, but we shouldn’t be. These events happen every year, we need pre-positioned supplies and community mapping.”, Key informant 1.

Chapter 6. Discussion

This study aimed to identify the diverse health impacts of ECEs on children under five in the Sahel and to inform program adaptation and emergency strategies for medical humanitarian organizations like MSF. It is important to note that mapping and predicting where each ECE is most likely to occur is not the primary subject of this paper. However, on a local level, assessing the likelihood of these ECEs is crucial before designing a proposed intervention strategy. The findings, derived from a synthesis of literature and KIIs, offer critical insights into the complex challenges and the nature of current humanitarian responses, emphasizing the need for more adaptive and integrated approaches.

- Demographic scope:

The scope of this study focused on children under five in Chad, Sudan, and northern Nigeria, three countries in the Sahel where MSF OCA operates. This allows for a deeper analysis of how ECEs affect a vulnerable group, revealing insights for program design. Children under five have physiological and developmental needs that make them disproportionately affected by climate-related health risks. The interventions targeted this group generally, with limited attention to particularly at-risk subgroups such as children with disabilities. This gap may reflect broader systemic challenges in healthcare access, where disability inclusion remains under-addressed. Also, extending the age focus could provide a broader picture, but would risk diluting the depth of analysis. Future research might well look into older children or pregnant women.

- Geographical scope:

While the Sahel is a broad region, the findings here offer a solid foundation for other countries in the region that face similar threats. However, applying these insights elsewhere requires careful contextualization. Among the three countries studied, (northern) Nigeria received the most research attention. This does not necessarily indicate that ECE's impacts are more severe there. Rather, it may reflect stronger research infrastructure, more international partnerships, or greater media and institutional visibility. In contrast, Chad, despite being heavily affected by ECEs, is underrepresented in the literature, likely due to limited funding and weak research systems. While some findings from Nigeria may be relevant to Chad and Sudan, extrapolation should be approached cautiously, as contextual factors like governance capacity and community resilience vary across these settings.

- Hazard scope:

While ECEs encompass a broad range of events like extreme heat, droughts, floods, wildfires, and storms, only limited data on wildfires and no data on storms were identified in the studied countries, reflecting research and surveillance gaps rather than the absence of these hazards. Wildfires and their associated consequences, such as air pollution, may be underreported or not prioritized as major public health concerns in the Sahel, unlike in countries like India, where wildfire-related health impacts are more prominent(105). The limited coverage of wildfires and storms in both the literature and KIIs suggests they are overlooked, possibly due to their perceived lower health impact or significance in this context, leading to reduced attention in research and response efforts.

- Health impacts of ECEs:

A striking realization is that although ECEs vary in type and intensity, their most pressing impacts on children in the Sahel often lead to common health challenges:

Malnutrition emerged as a major concern across all ECEs, reducing either food availability, food intake, or nutrient absorption, often all three, intensifying a high baseline vulnerability. Whether due to reduced agricultural output (droughts, floods), decreased caregiver capacity (extreme heat), or disrupted food systems. Similarly, diarrhea was widespread across droughts, floods, and heat events, reflecting fragile WASH infrastructure and the breakdown of hygiene systems. Access to healthcare was a recurrent obstacle, affected by road disruptions during floods and long travel distances during heatwaves. Healthcare access worsens across ECEs not just due to infrastructure damage but also behavioral shifts and systemic stress; families deprioritize care when survival becomes the focus.

A review of the literature shows that some health outcomes commonly linked to ECEs as cardiovascular disease or mental health impacts, were not reported in the studies included for this region and age group. This could reflect real epidemiological differences, under-recognition, or gaps in research and reporting. For example, while heat-related cardiovascular strain is well-documented among adults, especially the elderly(106), it may be underexplored in young children or not prioritized in settings with competing health burdens. Similarly, the psychosocial impacts of ECEs on young children, though potentially significant, remain unquantified in the current evidence base.

The background characteristics of affected populations can either heighten or reduce children's vulnerability to health impacts from ECEs. Rural residence, existing disease burdens, and maternal stress act as vulnerabilities, while protective factors such as breastfeeding and improved sanitation offer mitigation. KIIs highlighted how extreme heat strains caregiver capacity, leading to exhaustion that compromises care and feeding, further increasing malnutrition risk. ECEs can also disrupt health-seeking behavior, as exhaustion or shifting priorities may lead families to delay or avoid care, a critical yet under-researched issue.

- Emergency response and program adaptation strategies:

Despite commonalities in health risks, documentation and response vary significantly by ECE:

All ECEs affect children under five through these shared factors: nutritional, infectious, and access-related. While these factors pose risks during periods without ECEs, the intensity and scale of these risks are heightened during and after an ECE. This suggests that core health system reinforcements, nutrition screening, WASH integration, and mobile outreach are critical no matter the hazard.

Interventions mentioned for drought focused on improving access to healthcare through mobile clinics, early treatment of malnutrition (including screening, preventive supplements, treatment facilities, and training), and mitigating health risks through vaccination, WASH, and anticipatory action. However, adaptation efforts were limited. Few addressed risk factors made worse by climate change (multipliers), such as water scarcity or food insecurity, often seen as outside the medical mandate. Drought is a chronic humanitarian challenge in the Sahel, urging increased and sustainable efforts in the health, food, and development sectors.

Extreme heat had minimal institutionalized responses despite its impact on caregivers, service delivery, and newborns. This disparity can be explained by heat's invisibility as a "silent hazard," which contributes to its lack of programmatic attention, along with less documented direct

effects and insufficient infrastructure adaptation. Extreme heat adaptations were mostly improvised, such as shifting clinic hours, providing water, or planting trees, and were rarely embedded in formal humanitarian protocols. Medical humanitarian organisations have yet to integrate heat risk into preparedness or facility design. What is missing are structured heat action plans, climate-resilient infrastructure (e.g., ventilated clinics, shaded waiting areas), and targeted protocols for vulnerable groups like neonates. This reflects a need to integrate heat into medical humanitarian planning.

Meanwhile, floods visibly disrupted infrastructure and health service delivery. In response, medical humanitarian organizations primarily focused on restoring access to care, often through short-term solutions such as mobile clinics, rather than investing in long-term adaptation strategies. Despite rich multisectoral activity, interventions were rarely anticipatory. Critical gaps included weak institutional learning across recurrent flood events, limited investment in flood-resilient healthcare infrastructure, and underutilization of community-led innovations.

The vital role of community volunteers as first responders was highlighted. However, these volunteers are under-resourced and rarely integrated into humanitarian responses, representing a missed opportunity for effective and culturally appropriate interventions. Maternal exhaustion and caregiving capacity are rarely addressed by formal strategies; disability and mental health remain overlooked in both literature and practice, despite being exacerbated by ECEs.

Baseline healthcare systems in regions served by medical humanitarian organizations are often fragile, weakened by conflict, underfunding, corruption, infrastructural neglect, and workforce shortages. As a result, many adaptation efforts are ad hoc extensions of existing programming rather than newly developed or protocolized interventions(97). While operational flexibility allows for rapid response, the absence of institutionalized adaptation strategies limits long-term resilience.

National strategies, such as drilling boreholes, agricultural reform, and reforestation, fall outside the mandate of humanitarian medical NGOs but are essential components of a climate-health response. Larger-scale interventions in WASH, food security, and environmental management are indispensable to addressing the challenges that amplify the health impacts of ECEs.

By comparison, wildfires and storms received little attention in both the literature and KIIs, possibly indicating a blind spot in surveillance and response planning, or reflecting their limited impact or lower priority in the Sahel. This lack of data may point to weaknesses in climate-health monitoring, as such events are often localized, short-lived, or excluded from broader datasets(107,108).

While this review focused on adaptation and emergency interventions, the major ECEs were often perceived as chronic problems that should be addressed by longer-term development programming. This shift in focus could ensure sustained solutions to recurring challenges, rather than reactive responses to immediate crises.

- Strength of evidence:

While peer-reviewed literature offers a solid foundation on the direct health impacts of ECEs, its quantitative focus limits insight into indirect effects, such as psychosocial stress, caregiver strain, and systemic disruptions. These complex pathways are harder to measure but essential to understanding challenges and resilience.

Moreover, given the limited peer-reviewed evidence on effective adaptation and emergency interventions, this review included a broader range of sources, including grey literature and field reports. Across these, a gap emerged in the impact measurement attribution of interventions targeting child health outcomes during ECEs. The literature, while rich in programmatic details, predominantly described intervention delivery rather than evaluations of effectiveness. Interventions like early warning systems, vaccination campaigns, and reactive responses such as WASH kits, malnutrition treatment, or mosquito net distribution, though vital, are not unique to ECEs and are common across emergency settings(97). These interventions are often based on accepted best practices rather than evidence of their impact on ECE-specific health outcomes. For example, the provision of micronutrient powders and nutrient supplements is widely promoted, but their effect on climate-related food insecurity remains unmeasured.

Despite conducting only four interviews, KIIs provided rich insights. Their value lies in exposing implementation gaps, highlighting community-level adaptations, and revealing invisible burdens (e.g., maternal exhaustion, disability neglect) missed in broader literature because they are context-specific, difficult to quantify, and fall outside the scope of large-scale epidemiological studies. The convergence of messages among the few informants confirms significant weight to these qualitative findings, offering a crucial on-the-ground perspective on the need to improve access through mobile clinics, context-adapted strategies like adjusted clinic hours, strengthened infrastructure, and support for community-led responses.

Furthermore, the complexity and multisectoral nature of many interventions complicates efforts to evaluate their direct impact on health outcomes. This mirrors findings from a systematic review, which identified a lack of evidence on the causation of health effects and attribution of health interventions during humanitarian crises(109). While emergency health organizations already implement effective programs, like nutrition support, infectious disease care, and mobile outreach, these often need to be adapted for ECEs. To enhance the effectiveness of responses, there is a need for context-specific, evidence-based strategies and impact evaluations that go beyond general emergency protocols.

- Analytical framework:

The UNICEF framework was a valuable tool for organizing complex realities clearly, capturing domains such as hazards, impacts, multipliers, and vulnerabilities. Although this study did not focus primarily on multipliers and vulnerabilities, these elements emerged in both the literature and KIIs, reinforcing their relevance. A notable strength of the framework is its inclusion of service delivery constraints, such as infrastructural collapse.

The refinements enhanced the framework's contextual relevance. Simplifying it allowed for more targeted analysis, while adaptations, like reclassifying "changing vector patterns" as a health impact and introducing NDVI as a proxy for drought, strengthened its scientific utility.

However, a significant limitation of the framework is the absence of caregiver well-being. The KIIs revealed caregiver exhaustion as both a vulnerability (determining children's ability to cope) and a multiplier (factor made worse by climate change), impacting child health outcomes like malnutrition. This points to the need for future frameworks to include caregiver capacity as a determinant of resilience in climate-related crises.

- Strengths of the study :

-Provides an overview of the most frequent ECEs in the Sahel region.

-Highlights the associated health risks linked to these ECEs.

-Reveals a critical gap in evidence-based and protocolized interventions, highlighting the need for structured strategies.

-Qualitative component, though small, provided valuable insights.

- Limitations of the study :

-Geographic imbalance: Overrepresentation of (north) Nigeria; underrepresentation of Chad and Sudan due to conflict and limited research infrastructure.

-Limited community-based perspectives in the literature.

-Small number of interviews in the qualitative study, though triangulation helped enrich findings.

-Adaptation and emergency strategies are mostly based on program descriptions, introducing publication bias, as favored interventions are more likely to be reported than necessarily effective ones.

- Future Research Priorities :

-Identify the most effective combination of programs that can be applied across multiple ECEs.

-Study the nature and extent of Health behavior changes per ECE.

-Investigate mental health impacts of ECEs on children under five and caregivers, and how to address them.

-Investigate health risks from storms and wildfires in the Sahel.

-Conduct more research in Chad and Sudan

-Use participatory methods to integrate community perspective into analysis and planning.

Chapter 7. Conclusion

This study provided a consolidated, child-focused analysis of the health impacts of ECEs on children under five in the data-scarce Sahel region. It found that while different ECEs (heat, droughts, and floods) have a significant impact on child health, the resulting conditions, malnutrition, infectious diseases, and compromised access to healthcare, are consistent. The research highlighted critical gaps in humanitarian responses, noting that existing interventions are not ECE-specific, and key issues such as caregiver strain, mental health burdens, and the under-resourced role of community volunteers are largely unaddressed. The study demonstrated the need for more targeted research and context-driven approaches to improve child-focused interventions and preparedness, especially in regions where conflict and climate change overlap.

Chapter 8. Recommendations for medical humanitarian emergency organisations:

1)ECE Preparedness:

- Identify likely climate change scenarios in a specific area by combining local knowledge with scientific forecasts to guide proactive planning.
- Integrate nutrition surveillance with early warning systems and climate forecasts to strengthen anticipatory action and response.
- Develop protocols for specific ECEs to ensure accessibility to health care, including staff, stocks, clinic, and activity management.
- If triggered by surveillance, pre-position decentralized stocks of essential medical and nutrition supplies (therapeutic foods and micronutrients) to enable rapid response.

2)Adapt Health Service Delivery:

- Adjust clinic hours to avoid peak heat, ensure shaded waiting areas, and explore the feasibility of solar-powered cooling solutions in health facilities, especially for critical units like neonatal care.
- Strengthen human resources during peak heat and floods by reinforcing staffing in health facilities and mobile teams to prevent staff exhaustion and ensure continuous service delivery.
- Prioritize service delivery closer to communities by expanding adapted mobile clinics during heatwaves and floods, when people may not travel to fixed health facilities.
- Prioritize displaced children by integrating targeted outreach in displacement sites, ensuring continuity of care during ECEs.

3)Programming Priorities for ECEs:

- Catch-up vaccination campaigns for diseases like measles and pneumonia before ECEs, especially in displaced communities, to prevent outbreaks when access to care is disrupted.
- Ensure access to safe water and hygiene during and after ECEs by providing minimum water quantities, hygiene kits (e.g., soap), and water purification tablets to reduce the risk of diarrhea.
- Strengthen community-based malnutrition screening and referral systems to proactively identify and manage severe cases, while implementing supplementary feeding for all children under five to prevent malnutrition during ECEs.
- Intensify Mental Health Support for Children and Caregivers by:

Establishing accessible spaces for caregivers to access peer support and stress management.

Training health workers in Mental Health and Psychosocial Support tailored to crisis contexts.

4)Enhance Data Collection and Impact Evaluation:

- Standardize data collection tools to capture specific exposures to ECEs and link them to disaggregated health outcomes by age, gender, and displacement status. This will help identify the most vulnerable and guide targeted responses.

- Prioritize Impact Evaluations: Move beyond programmatic descriptions to prioritize impact evaluations of interventions. These evaluations should assess their effectiveness in reducing child morbidity and mortality specifically during or after ECEs, rather than relying on general protocols not specified for ECEs.
- Support Context-Specific Research: Actively support research in underrepresented countries like Chad and Sudan, and in complex, conflict-affected areas where ECE impacts are amplified by ongoing crises.

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Annexes :

Annex1: Search string for objective 1

1. **Climate Change / Environmental Factors/ Climate hazards AND**	2. **Population: children AND**	3. **Location: Sub-Saharan Africa AND**	4. **Child health impacts**
“Climate Change” OR “Climate variability” OR OR “Global warming” OR “Extreme weather” OR “Environmental Exposure” OR “Floods” OR “Droughts” OR “Hot Temperature” OR “Air pollution” OR “Heat waves” OR “Extreme heat” OR “Wildfires” OR “Extreme climate events” Or “Precipitation” OR “Rainfall” OR “Normalized Difference Vegetation Index” OR” storms”	"Child" OR "Infant" OR "Pediatrics" OR "under-five" OR "under 5" OR "pediatric*"	"Africa South of the Sahara" OR "Sub-Saharan Africa" OR "Chad" OR "Nigeria" OR "Sudan" OR "Sahel" OR "Sahelian”	“Neonatal health” OR “Infant health” OR “Child health” OR “Pediatric health” OR “Under-five health” OR “Under-5 health” OR “Malnutrition” OR “stunting” OR “wasting” OR “Infectious diseases” OR “Changing vector patterns” OR “vector-borne diseases” OR “malaria” OR “diarrheal diseases” OR “Cholera” OR “Kala Azar” OR “Dengue Fever” OR “Respiratory diseases” OR “Asthma” OR “Pneumonia” OR “Non Communicable Diseases” OR “Noncommunicable Diseases” OR “Mental health” OR “neurodevelopment” OR “Psychosocial effects” OR “Stress” OR “Psychological” OR “Anxiety” OR “Health Seeking Behavior” OR “Mental health” OR “growth retardation” OR “cognitive development” OR “breast feeding” OR “infant feeding”

Annex 2: Search string of Objective 2

Setting (S) AND	Perspective (P) AND	Intervention (I) AND	Comparison (Impact) (P) AND	Evaluation (E)
("Chad" OR "Nigeria" OR "Sudan" OR “Sahel”) AND NOT ("Asia" OR "Europe" OR "Latin America") AND ("extreme climate change events" OR ”extreme heat” OR “droughts” OR “floods” OR “Wildfires” OR “Storms” OR “Air pollution”)	"Children under five" OR "Pediatrics" OR "Neonates" OR "Infants" OR "lactating women") AND NOT ("adults only" OR "elderly" OR "children over five")	"Program adaptation" OR "emergency response" OR "Preparedness" OR "medical response" OR “intervention” AND NOT ("agriculture" OR "livelihoods" OR "infrastructure" OR "carbon reduction")	"Adverse birth outcomes" OR "Malnutrition" OR "Infectious diseases" OR "Mental health" OR “Non-communicable diseases” OR "Health" OR "Disease" OR "Epidemic" OR "Diarrhea" OR "Cholera" OR "Measles" OR "Malaria" OR “changing vector patterns” OR "Undernutrition" OR "Underweight" OR "Small for date" OR "Pre-term" OR "Breastfeeding"	"Program evaluation" OR "field study" OR "impact description") AND NOT ("theoretical model" OR "policy-only" OR "advocacy report")

Annex 3:

Interview guide:

Section 1: Background Information

0. Introduction: This interview is part of a study that explores how extreme climate events such as floods, droughts, extreme heat, wildfires, air pollution (although it is not an ECE) are impacting the health of children under five in the Sahel (mainly Chad, Sudan and north Nigeria where MSF OCA works), and to identify strategies that can help MSF and similar organizations better adapt to emerging challenges.

The purpose of this interview is to deepen our understanding by complementing the literature with the perspective and reality directly seen in the field. You have been invited because of your expertise, your critical role within MSF (or related institutions), and your valuable perspective on health issues in climate-affected settings. Your insights will help to complement the literature findings and identify potential factors that may support humanitarian NGOs in shaping strategies to reduce the health impacts of extreme climate events on children under 5 in the Sahel.

1. Can you briefly describe your role and experience with MSF's work? How does your work relate to or involve issues of climate change and child health??

Section 2: Perceived Impact of Climate Change on Children's Health

2. Based on your experience in the Sahel (like in Sudan, Chad, Nigeria), do you observe any effects of extreme climate change events in this region? If so, how do you think these ECE (floods, droughts, extreme heat…)are impacting the health of young children? And where?

3. Among the health problems linked to climate change in children, which do you think are the most urgent or concerning?

4. Are there specific regions or populations in Chad, Sudan, or Nigeria that are more vulnerable to these impacts? Like pastoralists, specific regions, or any specific age group. If so, why?

Section 3: Current MSF Strategies and Gaps

5. What strategies or interventions has MSF implemented to address the impact of extreme climate change events on child health?

6. Have these strategies been effective? What challenges or limitations have you observed in their implementation?

7. Given MSF's role as a humanitarian medical organization, are there any good practices or successful approaches you think MSF can adopt to better respond to these climate-related health challenges?

Section 4: Validation of Preliminary Findings

8. Based on preliminary findings from the literature review, several priority areas have been identified where MSF could strengthen or adapt its response to better address the health impacts of extreme climate events on children under five in the Sahel. From your field

experience, what interventions seem appropriate to address health issues related to ECE? Are there any that you would prioritize more, adapt, or consider less relevant in your context? And then use this list for probing:

• Intervention strategies currently implemented across Chad, Nigeria, and Sudan:

o Mobile clinics in hard-to-reach areas

o Vaccination campaigns during outbreaks

o WASH kits & water chlorination

o Nutrition programs (/Outpatient Therapeutic Feeding Center, supplementary feeding, mother support groups)

o LLIN distribution & malaria prevention

o Psychosocial support & child-friendly spaces

o Community-based education (e.g., infant feeding)

o Solar-powered health posts (e.g., in Sudan)

Are there any gaps or additional strategies you think MSF or similar organizations should consider?

9. Do you see any gaps or other important aspects we might have missed and should consider in this area? Like something for pregnant and lactating women

We're especially interested in hearing about groups or factors that may not be fully addressed in current strategies.

(Probing suggestions, if needed)

Section 5: Final Thoughts

10. If you could make one recommendation to MSF regarding extreme climate change events and children's health, what would it be?

12. Is there anything else you would like to add that we haven't discussed?

Annex4:

Informed consent

Study Title: Exploring the Health Impacts of Extreme Climate Events on Children Under Five in the Sahel: Toward Adaptive Strategies

Principal Investigator: Emna Hariz

Thesis Advisor:

Academic Advisor: Yasmine El Addouli

Affiliation: Master of Science in Public Health and Health Equity, KIT Royal Tropical Institute, Amsterdam, The Netherlands

Introduction

You are invited to participate in a research study that aims to identify actionable factors to mitigate the impact of climate change on children's health in Sub-Saharan Africa. This study is conducted as part of the MSF Thesis Topic Opportunity (Environmental Health). Before you decide whether to participate, please read this document carefully and feel free to ask any questions.

Purpose of the Study

The study seeks to gather insights from experts in public health, environmental health, pediatric diseases, and humanitarian response to better inform MSF's priorities and challenges in mitigating climate-related health risks for children.

What Participation Involves

If you agree to participate:

You will be asked to take part in a semi-structured interview lasting approximately 30–45 minutes.

The questions will focus on your professional expertise regarding children's health, climate-related extreme events, malnutrition, infectious diseases, and related topics.

Your participation is completely voluntary, and you may refuse to answer any question or withdraw at any time without consequences.

Confidentiality and Data Protection

No personally identifiable information (such as names, locations, or job titles) will be published.

Data will be stored securely and accessible only to the research team.

Responses will be analyzed in aggregate form to ensure anonymity.

The findings may be used in academic or organizational reports, but individual responses will not be traceable.

Potential Risks and Benefits

There are no foreseeable risks to your participation, as the study focuses solely on professional perspectives and does not involve sensitive personal topics.

Your insights will contribute to a better understanding of climate change's impact on children's health and help inform MSF's humanitarian strategies.

Voluntary Participation and Right to Withdraw

Your participation is entirely voluntary. You can withdraw from the study at any time without explanation, and any data collected up to that point will not be used.

Contact Information

If you have any questions about this study, please contact:

Emna Hariz (Principal Investigator) – [e.hariz@student.kit.nl]

Consent Statement

I have read and understood the above information about the study. I have had the opportunity to ask questions, and I voluntarily agree to participate.

Participant's Name:

Participant's signature :

Annex 5: AI use Declaration

Check the box that applies to your completion of this assignment:

☐ I confirm that **I have not used** any generative AI tools to complete this assignment.

☒ I confirm that **I have used** generative AI tool(s) per the "**Guidelines for the use of Generative AI for KIT Institute Master's and Short course participants".** Below, I have listed the GenAI tools used and for what specific purpose:

Generative AI tool used	Purpose of use
1. Perplexity	To refine my research questions and objectives, and brainstorm during my initial topic choice,
2. Chat GPT	To brainstorm ideas about my discussion, for conceptual clarification, and queries on unfamiliar concepts
3. …	

Annex 6: Overview of 26 Studies Examining Climate Extremes and Health Impacts in Northern Nigeria, Chad, Sudan

Author (year)	Study design	Country	Climate-related hazard	Health outcome	Key finding
Andriano (2023)	Cross-sectional study	Nigeria (from Sub-Saharan-wide study)	Extreme heat	Low birthweight	Heatwave exposure during pregnancy reduced birthweight.
Flückiger and Ludwig (2022)	Repeated cross-sectional surveys	Nigeria and Chad (from the Sub-Saharan-wide study)	Extreme heat	Diarrhea, Malnutrition	Higher short-term temperatures were associated with increased diarrhea and wasting.
Marshak et al. (2023)	Longitudinal study	Chad	Extreme heat	Malnutrition	Hotter temperatures increased and reduced the WHZ score.
Brimicombe et al. (2024)	Longitudinal study	Nigeria (pooled with Burkina Faso and Southern Ghana)	Extreme heat	All-cause child mortality	Extreme heat was associated with reduced child mortality for children aged 1 month to 5 years; no effect was observed for neonates.
Sandler and Sun (2024)	Cross-sectional study	Nigeria	Extreme heat	Malnutrition	Sustained high temperatures (e.g., 38°C) were linked to higher child wasting prevalence
			Low NDVI	Malnutrition	A 1-unit NDVI is associated with a 9.2% lower probability of child wasting
			Precipitation anomalies (droughts or extreme rainfall)	Malnutrition	Rainfall anomalies were linked to an 11.8% increase in stunting
Van der merwe et al. (2022)	Longitudinal study	Nigeria	Extreme heat	Malnutrition	Higher temperatures were linked to increased stunting and underweight in children under 5 in Nigeria.
			Droughts	Malnutrition	Decreasing precipitation increases the risk of stunted growth and underweight children.
Kemajou (2022)	Cross-sectional study	Nigeria and Chad (from the Sub-Saharan-wide study)	Extreme heat	Diarrhea	Each 1°C increase in temperature is associated with a 6.7% rise in diarrhea cases, with a greater impact in households lacking improved water and sanitation.

			Extreme rainfall	Diarrhea	Extreme rainfall increased diarrhea risk by contaminating water sources, especially where sanitation is poor.
Dunn et al. (2019)	Cross-sectional study	Nigeria (from a West African study)	Extreme heat	Diarrhea	Lower temperatures were associated with reduced child diarrhea risk, possibly due to decreased fly activity and less pathogen concentration in water.
McElroy et al. (2022)	Case-crossover study	Nigeria (as part of a lower-middle-income countries study)	Extreme heat	Preterm birth	Exposure to high temperatures 0–1 day before delivery significantly increased the risk of preterm birth
Ugwu and Zewotir (2020)	Cross-sectional study	Nigeria	Extreme heat	Malaria	Extreme heat and low temperature variation are associated with reduced malaria prevalence, likely due to disrupted mosquito development.
			Extreme rainfall	Malaria	Extreme wet events are linked to increased malaria prevalence.
Thiede and Strube (2020)	Cross-sectional study	Nigeria (from the Sub-Saharan-wide study)	Extreme heat	Malnutrition	Heatwaves increase child wasting risk by 8.1%; rural and urban children are equally affected by high temperatures
			Droughts	Malnutrition	Droughts were linked to a 35.6% drop in WHZ scores.
			Extreme rainfall	Malnutrition	Excessive rainfall was mildly associated with increased risk of child wasting.
Adewoyin et al. (2023)	Narrative review	Nigeria (from Sub-Saharan-wide study)	Extreme heat	Malnutrition and other climate-related illnesses	In Southwest Nigeria, frequent heatwaves increased child malnutrition and affected 72.2% of hospitalized children under 5 with climate-related illnesses; female children were more affected.
			Droughts	Malnutrition and other climate-related illnesses	Droughts increased malnutrition risk, while rainfall influenced 72.2% of under-five hospitalizations for climate-related diseases.
Badr et al. (2023)	Cross-sectional study	Nigeria (from a global study)	Extreme heat	Shigella infection	Extreme heat was associated with reduced Shigella infection rates

			Extreme rainfall	Shigella infection	Extreme rainfall increased Shigella risk only when preceded by soil moisture.
Opoku et al. (2021)	Cross-sectional study	Nigeria (from a regional study)	Extreme heat	Heat rashes	In West, East, and Southern Africa, including Nigeria, children under five are among the most affected by heat rashes because of extreme heat
Dimitrova et al. (2022)	Cross-sectional study	Nigeria and Chad (from a global study)	Droughts	Infectious diseases	In countries like Chad and Nigeria, anomalously dry conditions were associated with an increased risk of fever in children.
			Extreme rainfall	Infectious diseases	In countries like Chad and Nigeria, Extreme rainfall was linked to lower fever risk
			Precipitation anomalies (droughts or extreme rainfall)	Infectious diseases	Nigeria: Precipitation anomalies were linked to more diarrhea in children and lower fever risk in tropical savanna areas no clear association with cough or in dry zones. Chad: No associations between rainfall anomalies and fever, cough, or diarrhea across climate zones.
Njatang et al. (2023)	Cross-sectional study	Nigeria	Drought/ Low NDVI	Malnutrition	In Nigeria's Sahel, droughts (low NDVI/rainfall) raise child underweight, while vegetation growth is protective.
Rustad et al (2019)	Cross-sectional study	Nigeria (from a Sub-Saharan African study)	Drought	Malnutrition	Drought significantly worsens child waste, especially in the north, reducing WHZ scores and erasing the usual nutritional advantage of younger children, highlighting the compounding effects of climate stress and structural inequities.
Dunn and Johnson (2018)	Cross-sectional study	Nigeria (from a West African study)	Drought	Diarrhea	Drought during 2011–2013 may explain the high diarrhea risk in northern Nigeria.
Tirado et al. (2015)	Narrative review	Sahel	Drought	Malnutrition	Male drought-related migration in the Sahel increases women's caregiving burden, raising the risk of child undernutrition.

Thomson et al. (2017)	Ecological study	Sudan and the Sahel in general	Drought	Malaria	Droughts in the Sahel during the 1970s–1980s were associated with reduced malaria, while the recent shift to wetter conditions has increased climate suitability for malaria transmission.
Uttajug et al. (2023)	Cross-sectional study	Nigeria	Extreme rainfall	Acute Respiratory Infections	Extreme rainfall increased childhood acute respiratory infections, likely via flooding-induced indoor crowding, displacement, and exposure to pathogens.
Balikuddembe et al. (2023)	Ecological study	Sudan	Floods	Malaria	Longer flood durations were significantly linked to fewer malaria cases, but this inverse relationship likely reflects complex interactions with other overlapping climate hazards, not a protective effect of floods.
Denue et al. (2018)	Outbreak investigation	Nigeria	Floods	Cholera	The cholera outbreak in Jere Local Government Area (LGA) was linked to heavy rainfall and flooding; it rapidly spread to 4 neighboring LGAs. Under-5 Case Fatality Rate: 0.9%
Ogburia et al. (2024)	Narrative review	Nigeria	Floods	Cholera	Cholera outbreaks in Nigeria have affected 32 states, with children under five being the most vulnerable group, exacerbated by flooding and poor sanitation.
Aborode et al. (2025)	Case study	Nigeria	Floods	Cholera	Flooding worsened existing spikes in diarrhea and malaria cases among children and led to new cholera infections.
				Other infectious diseases	Flooding in Nigeria increases infectious diseases like cholera, dengue, and malaria among 1.6 million malnourished children, worsening the malnutrition-infection cycle.
				Malnutrition	Flooding and conflict in Borno State have worsened food insecurity, leading to a sharp rise in severe acute malnutrition among children, increasing their risk of illness and death.
				Health seeking behavior	Flooding in Borno State has damaged key infrastructure and cut off access to affected communities, delaying aid delivery and healthcare access for children, thereby worsening malnutrition and increasing child mortality.
Xue et al. (2021)	Case-control study	Nigeria and Chad (from allow and middle-income countries study)	Wildfires	Child mortality	Fire-related $PM_{2·5}$ exposure is linked to increased child mortality, with stronger evidence in high-exposure settings like Chad and a moderate but still concerning association in Nigeria.