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## RESEARCH ARTICLE

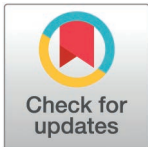
# A scoping review of natural disasters, environmental hazards, and maternal health: Are all potential outcomes accounted for in conceptual frameworks?

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## Abstract

Natural disasters and extreme weather events are increasing in frequency and intensity, in part due to climate change. These events can have severe impacts, including on maternal health. We review the existing research on natural disasters, environmental hazards, and maternal health outcomes – focusing specifically on relevant conceptual frameworks and termination of pregnancy as an outcome of these events – published between January 2004 and May 2024. We retrieved eight frameworks and 26 additional research articles. None of the frameworks identified pregnancy termination as an outcome of natural disasters, though there is ample evidence to suggest that pregnancy termination and related outcomes must be included in these frameworks. We propose a new, comprehensive framework in which all reproductive outcomes with the potential to affect maternal morbidity or mortality, including pregnancy termination (i.e., induced abortion), are considered. We hope that the **Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO)** framework will inform emergency response planning to improve service delivery that empowers individuals to make informed reproductive health choices in the wake of these crises.

## OPEN ACCESS

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## Introduction

Over the last fifty years, the world has experienced a surge in natural disasters, in part due to climate change [1]. Climate change is increasing both the frequency and intensity of extreme weather events and also altering spatial and temporal patterns of exposure [2]. Heavy precipitation and high temperature extremes have become more common in recent decades; hot seasons are arriving sooner and lasting longer; tropical cyclones are increasing in frequency and are reaching peak intensity at new latitudes; and sea levels are rising across the globe, all of which are driven in part by human-induced climate change [3–5]. Even more concerning is the role climate change has likely played in increasing the frequency of compound events, including concurrent heatwaves and droughts, fire weather, and compound flooding incidents

[3]. The cascading impacts of these phenomena heighten the risk of disaster and other emergencies, particularly in already vulnerable communities [1,2].

Natural disasters and environmental hazards can have severe and adverse impacts on health, including sexual and reproductive health (SRH) [4,5]. Severe flooding, for example, has been associated with increased rates of gestational hypertension and pregnancy loss [6,7]. Similarly, hurricane exposure has been linked to maternal stress and a range of adverse pregnancy outcomes, including fetal death [8,9]. High temperature extremes have been associated with increased risk of severe maternal morbidity, as well as an array of undesirable birth outcomes, including stillbirth and preterm birth [10]. Exposure to wildfire smoke may increase the risk of preterm birth and birth defects [11,12]. Disaster-related trauma and/or displacement can also create both physical and psychological burdens that weigh particularly heavily on pregnant women [13]. Moreover, disasters can interfere with service delivery, contraceptive availability, and access to care. Flooding has, for example, in some regions, limited access to maternal healthcare, menstrual regulation (a program in Bangladesh that restores a woman's menstruation 10–12 weeks after a missed period without the use of a pregnancy test), and post-abortion care [9,14]. And there are documented incidents of healthcare providers turning away both women in labor and women seeking long-acting reversible contraceptive methods due to clean water shortages resulting from disasters [15]. There is a growing body of research that explores these connections between natural disasters and reproductive health, some of which suggests a link between a woman's experience of disaster and fertility decision-making [3,16]. Given this emergent data, we sought to assess pregnancy termination (i.e., induced abortion) as an outcome following natural disasters. In particular, we sought to contribute to current efforts to improve disaster response by assessing how this information is – or isn't – included in existing frameworks focused on reproductive health in these contexts.

In this manuscript, we review the existing research on natural disasters and reproductive health outcomes, focusing specifically on (A) relevant conceptual frameworks and (B) pregnancy termination as an outcome within these frameworks. Ultimately, we propose a new, comprehensive framework in which all reproductive outcomes with the potential to affect maternal morbidity or mortality, including pregnancy termination, are considered – the Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO) framework. We hope that our findings might help guide the implementation of broader risk reduction strategies, like the World Health Organization's Health Emergency and Disaster Risk Management Framework [17] and the United Nations' Sendai Framework (2015–2030) [18], by providing both evidence and guidance to support the improvement of maternal health services in disaster settings.

## Materials and methods

### Terms and definitions

The language used in this review adheres to the standard set by the World Health Organization, UNICEF, the United Nations Population Fund, and the Human Reproduction Programme in their November 2023 call for action to protect maternal, newborn, and child health from the impacts of climate change [19]. Throughout the manuscript, as in the aforementioned call for action, “the term “women” is used to refer to all those who identify as women regardless of sex assigned at birth. However, it is recognized that there are other gender-diverse individuals who do not identify as women but who have reproductive capacity. The intention is not to exclude their experiences but reflects the current lack of data identifying and/or reflecting the specific experiences of gender-diverse individuals” [19].

Throughout the manuscript, we use the term “natural disaster” to capture geophysical, hydrological, meteorological, and climatological disasters, as defined by the NatCatSERVICE database [20]. We also include related climate and environmental hazards with the potential to cause disasters – for example, heavy precipitation or temperature extremes – in our search. According to the Sendai Framework (2015–2030), a hazard is an event with the risk of negative impact, and the precursor to disaster [18]. When a hazardous event causes serious disruption of a community or society, at any scale, leading to human, material, economic losses and/or impacts, it becomes a disaster [21].

We define “framework” broadly and also include in our review visual maps and related images that depict causal relationships between exposure to environmental hazards and adverse maternal outcomes.

We use the terms “induced abortion” and “pregnancy termination” interchangeably to refer to abortions that are brought on deliberately through an intervention (medication or procedural). We use the terms “spontaneous abortion” and “miscarriage” to refer to abortions that are unforced and/or caused by accident.

## Scoping review

**Search strategy.** We conducted a scoping review of the literature to identify conceptual frameworks that explore the relationship between natural disasters or environmental hazards and maternal health. We report our scoping review according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR).

We first searched PubMed and CINAHL databases on 29 April 2024 for English language original research articles with relevant frameworks published from January 2004 through February 2024; we again searched PubMed on 15 June 2024 and CINAHL on 23 June 2024 to capture additional frameworks published through May 2024. We used the following maternal health related search terms: *abortion*, *“birth outcome”*, *gestation*, *maternal*, *miscarriage*, *perinatal*, *postpartum*, *post-partum*, *post-natal*, *postnatal*, *pregnancy*, *“pregnancy complication”*, *“pregnancy loss”*, *“pregnancy outcome”*, *“premature birth”*, *“prenatal”*, *“preterm birth”*, *puerperal*, *stillbirth*. We combined the above search terms with terms related to natural disasters and environmental hazards: *avalanche*, *blizzard*, *“coastal flooding”*, *“cold wave”*, *“cold spell”*, *cyclone*, *drought*, *earthquake*, *“environmental disaster”*, *“environmental emergency”*, *“extreme temperature”*, *fire*, *flood*, *“geological hazard”*, *hail*, *“heat wave”*, *heatwave*, *hurricane*, *hydrometeorological*, *“ice storm”*, *landslide*, *“land slide”*, *lightning*, *mudslide*, *“natural disaster”*, *“seismic activity”*, *storm*, *“storm surge”*, *“strong wind”*, *tornado*, *tsunami*, *typhoon*, *wildfire*, *volcano*, *“volcanic eruption”*. We used the following search terms to identify articles with relevant frameworks: *model*, *framework*, *conceptual*, *flowchart*, *“conceptual model”*. Search terms in each category were combined using the Boolean operator, “OR”, and across topics using the Boolean operator, “AND”. We also conducted manual and citation searches to locate additional sources.

**Search results screening and data extraction.** We imported all results into Covidence for screening [22]. Following the removal of duplicates, we screened titles and abstracts for their exploration of the relationship between natural disasters and/or environmental hazards and maternal health outcomes. We then conducted a full text review of the remaining articles that were available online. Specific criteria for inclusion or exclusion of frameworks are included in Table 1. We selected these criteria to best represent a broad range of frameworks relevant to the topic of natural disasters and environmental hazards and maternal health outcomes.

We extracted the following data from articles included in this review: title, author(s), publication year, purpose of framework, type of disaster, outcome(s) assessed, and inclusion of voluntary pregnancy termination (yes/no).

**Table 1. Inclusion and exclusion criteria for frameworks included in this scoping review.**

Inclusion criteria	Exclusion criteria
<ul style="list-style-type: none"> <li>• Conceptual framework about geophysical, hydrological, meteorological, and/or climatological disasters or related hazards</li> <li>• Framework includes maternal health outcomes</li> <li>• Published from January 2004 through May 2024</li> <li>• Published in English</li> <li>• Available online</li> </ul>	<ul style="list-style-type: none"> <li>• Conceptual framework exclusively about biological disasters (i.e., infectious disease epidemics) or non-natural disasters (i.e., chemical spills)</li> <li>• Framework exclusively about infant or child health, non-health outcomes, or single maternal health outcomes</li> <li>• Frameworks focused on interventions</li> <li>• Frameworks lacking causal pathways</li> <li>• Published before 2004 or after May 2024</li> <li>• Not published in English</li> </ul>

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## Maternal health outcomes of natural disasters and environmental hazards

We conducted additional targeted searches on PubMed and Google Scholar to identify research articles relevant to pregnancy termination as an outcome of natural disasters. We specifically looked for studies that explored disruptions to maternal and SRH services, including all obstetric and delivery services at any level of the health care system, changes in contraceptive use, sexual- and gender-based violence (SGBV), unintended and/or unwanted pregnancies, induced abortion, and fertility decision-making as a result of natural disaster. We searched for these related outcomes due to their direct linkage on the pathway from natural disaster or environmental hazard to induced abortion and maternal morbidity and mortality. We included articles published in the English language in the past twenty years (i.e., from January 2004 through May 2024).

## Presentation of results

In our results section, we first present the outcome of our scoping review. We divide broad frameworks from those that explore heat exposure impacts on maternal outcomes, a decision which we describe in the relevant section of the manuscript. We then describe the results of the additional searches we conducted to find evidence supporting the inclusion of abortion as an outcome of natural disasters and environmental hazards. Lastly, we present a new framework.

## Results

### Scoping review

We captured a total of 915 records published between January 2004 and May 2024. Our initial search, conducted 29 April 2024, yielded 846 papers published between January 2004 and February 2024 on PubMed (n = 741), CINAHL (n = 101), and through hand and citation searching (n = 4). Our second search, conducted on 15 June 2024 (PubMed, hand search) and 23 June (CINAHL), yielded 69 additional publications on PubMed (n = 40), CINAHL (n = 28), and via hand search (n = 1).

We removed 116 duplicate articles and screened the remaining 799 article titles and abstracts. Following screening, 154 articles remained for full text review. Two studies were not retrievable online and were therefore excluded. We removed studies that did not include a framework (n = 125). We excluded frameworks that focused exclusively on child or infant health outcomes (n = 11), non-health outcomes (n = 2), and frameworks that addressed only a single health outcome (n = 2). We also excluded frameworks that focused on interventions (n = 3) and frameworks that did not include a causal pathway (n = 1). We include eight frameworks in our final sample. [Fig 1](#) illustrates each step in the screening process.

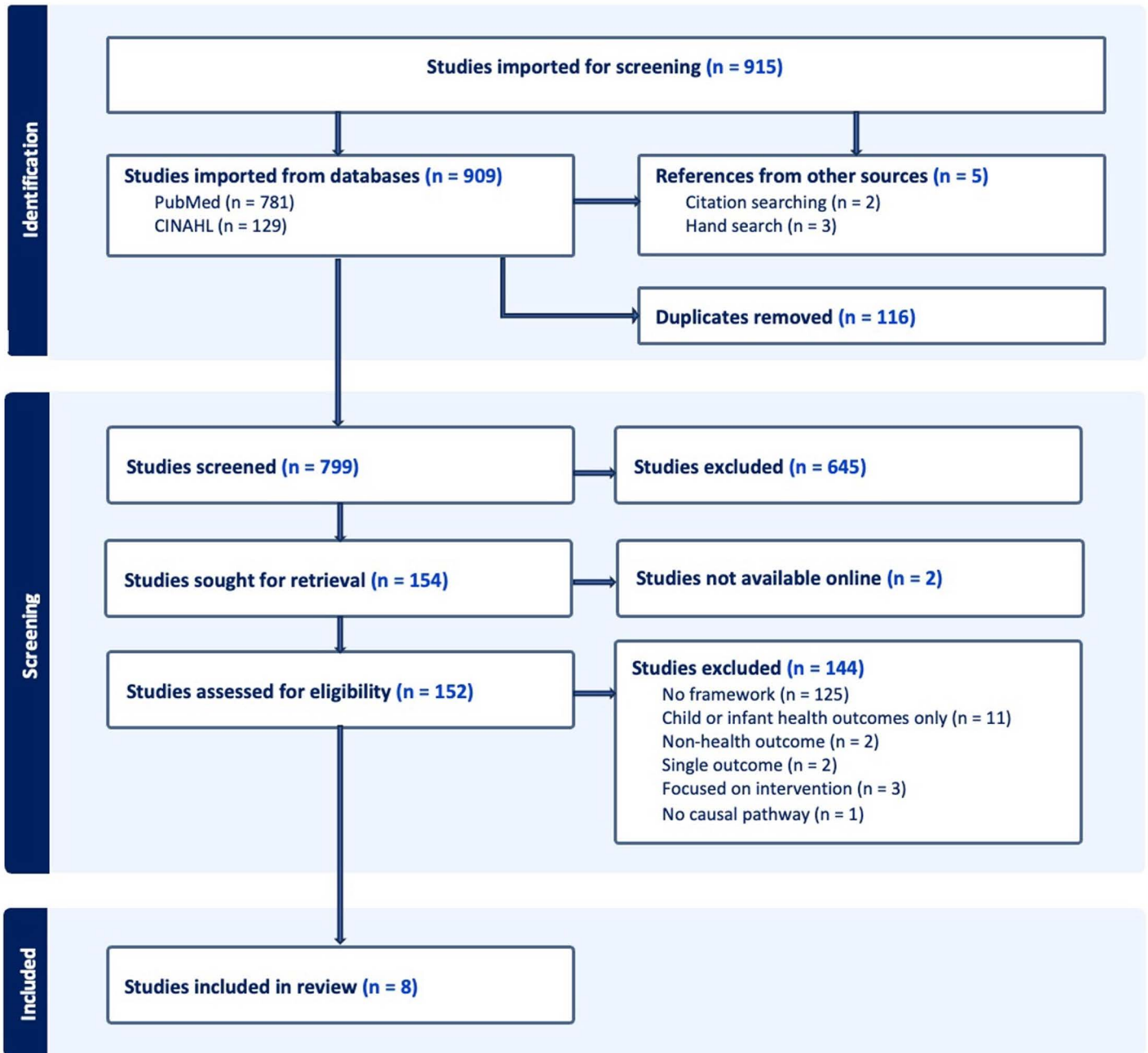


Fig 1. Identification, screening, and inclusion of research articles in this scoping review.

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Three of the identified frameworks address maternal health outcomes within a broad climate and/or disaster context; one of the frameworks focuses specifically on earthquake exposure; and four frameworks focus on heat-specific exposures. Despite our twenty-year search period, all studies included in the final synthesis were published in the past three years. An overview of the frameworks included in our scoping review are available in [Table 2](#).

**Table 2. Overview of frameworks included in the scoping review.**

Title	Authors (year)	Purpose of framework	Disaster/hazard type(s)	Outcome(s)	Inclusion of pregnancy termination
Assessing The Effects Of Disasters And Their Aftermath On Pregnancy And Infant Outcomes: A Conceptual Model	Harville, et al. (2021) [23]	To illustrate short- and long-term causal effects of disasters on pregnant women and their infants	All disasters (as defined by the World Health Organization), including natural and technological disasters	Maternal and infant morbidity and mortality	No
Conceptual Framework For Extreme Heat And Maternal, Newborn, And Child Health	HIGH Horizons, World Health Organization (2024) [24]	To depict the direct (pathophysiological mechanisms) and indirect (individual, community, and health services) pathways through which heat exposure can lead to adverse maternal, newborn, and child health outcomes	Heat and heat-related hazards	Maternal, fetal, newborn, and child health outcomes	No
Increasing Global Temperatures Threaten Gains In Maternal And Newborn Health In Africa: A Review Of Impacts And An Adaptation Framework	Chersich, et al. (2022) [25]	To outline pathophysiologic processes and indirect impacts of high ambient temperatures on maternal and newborn health	High ambient temperatures	Adverse maternal and newborn health outcomes	No
Influence Of Temperature On The Risk Of Gestational Diabetes Mellitus And Hypertension In Different Pregnancy Trimesters	Qian, et al. (2023) [26]	Graphical abstract of the relationship between temperature extremes and hypertensive disorders of pregnancy	Temperature extremes	Gestational diabetes mellitus and hypertension	No
Natural Disasters Resulting From Climate Change: The Impact Of Hurricanes And Flooding On Perinatal Outcomes	Suter, et al. (2023) [27]	To illustrate the interactions between underlying causal factors of climate change (e.g., fossil fuel use, resulting in increased atmospheric greenhouse gas emissions of carbon dioxide and methane) and adverse maternal health during pregnancy and childhood outcomes	Climate change, storms, and flooding and cascading impacts (food scarcity, migration, damage to the built environment and healthcare systems) and environmental chemicals and pollutants	Adverse maternal and child outcomes	No
Pregnancy And Newborn Health: Heat Impacts And Emerging Solutions	Bekkar, et al. (2023) [28]	To illustrate the population-level perinatal heat-health burden	High ambient temperatures	“Subtle” health impacts Labor and delivery triage and emergency visits Newborn mortality or severe maternal morbidity	No
Relation Of Disaster Exposure With Maternal Characteristics And Obstetric Outcomes: The Tohoku Medical Megabank Project Birth And Three-Generation Cohort Study	Ishikuro, et al. (2023) [29]	To help visualize the association between both the direct and indirect effects of disaster exposure and hypertensive disorders of pregnancy	Great East Japan Earthquake of 2011	Hypertensive disorders of pregnancy	No
The Changing Climate And Pregnancy Health	Ha (2022) [30]	To conceptualize climate impacts on maternal health during pregnancy via three pathways: (A) direct impacts via discrete environmental disasters, (B) indirect impacts through changes in the natural environment, and (C) indirect impacts through changes in the social environment	Impacts of climate change, including direct impacts (heat-waves, wildfires and extreme weather events like drought, hurricanes, floods) and indirect impacts (air pollution, food scarcity and water contamination, conflicts due to resources scarcity, displacement)	Adverse maternal outcomes	No

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## Broad frameworks relating natural disasters and/or environmental hazards to maternal health outcomes

The framework by Harville, et al. (2021) is arguably the most relevant for the purposes of this review [23]. Within the framework, the authors explore a broad range of both natural and technological disasters and their implications for maternal and infant health. The framework divides the impacts of these events into both short- and long-term outcomes and highlights the ways in which disasters can exacerbate existing social, environmental, and health disparities. The scope of the framework is limited to consideration of impacts on women who were already pregnant at the time of disaster and so does not include information about unintended or unwanted pregnancies. The framework fails to consider the causal relationship between miscarriage and maternal morbidity and mortality; and it does not explicitly incorporate stillbirth, though this outcome is addressed in the article in which the framework is embedded. Finally, Harville's framework does not include any information about changes in fertility preferences and does not include induced abortion as an outcome following disasters for individuals who are pregnant at the time of the disaster.

Suter, et al.'s framework (2023) articulates the interactions between underlying causal factors of climate change (i.e., fossil fuel use) and adverse maternal and child outcomes [27]. It considers the ways in which climate-driven disasters like extreme weather events might lead to these undesirable outcomes through mediators such as food scarcity, migration and the resulting loss of community, and damage to the built environment and healthcare facilities and systems. The framework does not articulate specific adverse maternal or child outcomes, though the source paper addresses some of those covered in the existing research. The authors acknowledge that one limitation of the existing research is the tendency to report only live birth outcomes, and therefore to exclude both induced and spontaneous abortion outcomes. The framework does not reference abortion or changing fertility preferences as possible outcomes related to climate change.

Ha's (2022) framework is somewhat similar to Suter et al.'s in that it addresses adverse outcomes in the broader context of climate change and related disasters. Specifically, this framework provides a helpful visualization of climate impacts on pregnancy health via (A) direct impacts through discrete environmental disasters, (B) indirect impacts through changes in the natural environment, and (C) indirect impacts through changes in the social environment [30]. The framework not only explores the ways in which these impacts interact with and exacerbate one another, but also addresses the broader contexts in which these impacts occur, including health system contexts, social and physical environmental contexts, and individual biological and behavioral contexts. The framework's scope is exclusive to adverse pregnancy outcomes, though a second figure in the paper further contextualizes these outcomes within the broader cycle of health impacts from pregnancy to birth, through adolescence to adulthood, and back to pregnancy again. Neither figure includes outcomes related to changes in fertility preferences or pregnancy termination.

**Earthquake frameworks.** Only one article specifically explores the effects of an earthquake on our outcome of interest. The model presented in Ishikuro, et al. (2023) presents empirical data about maternal health outcomes following a specific disaster exposure, a 2011 earthquake in Japan [29]. It is the only figure to include data resulting from targeted mediation analyses, and the only figure to provide a specific timeline regarding pre-pregnancy disaster exposure and related outcomes. Moreover, it is narrower than many of the others in that it considers only one subset of maternal health outcomes, hypertensive disorders of pregnancy (HDPs). As elective pregnancy termination does not fall within the range of HDPs, it is not included in the framework.



**Heat-specific frameworks.** Four of the frameworks included in this review exclusively explore the effect of heat-specific exposures on maternal health outcomes. While we recognize that not all heat exposures or temperature increases are natural disasters themselves, we include these in our review because there is clear and widespread evidence to suggest that high temperatures can exacerbate the risk of disaster and can themselves become disasters or emergencies, as in the case of heatwaves [2,31].

There is ample evidence to support the association between heat exposure and adverse impacts on maternal health [32–34]. Still, we recognize that the manifestation and related impacts of heatwave disasters – and individual and community responses to these events – can differ greatly compared to other types of natural disasters. For example, heatwaves on their own may cause less immediate and extensive displacement than other natural disasters, such as severe flooding [35]. Though this in no way implies that heat is any less of a threat to maternal health, we acknowledge that it could mean that heat may act differently on fertility preferences as compared to other disasters. And while research on fertility determinants indicates that seasonal patterns in live births may be associated with both behavioral and biological responses to temperature change or temperature extremes, there exists limited understanding of the pathways through which these mechanisms act [36].

We further acknowledge that there exists very little information linking heat exposure to pregnancy termination – and where these studies do exist, we were unable to identify any that referenced datasets differentiating between spontaneous and induced abortion [36,37]. However, given the role of temperature in climate impacts and natural disasters more broadly, in combination with our goal of ensuring that these frameworks capture all relevant outcomes, we feel that it is appropriate to include these frameworks in our review due to their potential impact on pregnancy decision-making and demonstrated impact on other maternal health outcomes.

The newest framework and most comprehensive heat-related framework in our sample, “Extreme heat and maternal, newborn and child health” is a product of the combined work of HIGH Horizons – a European Union-based project consortium – and the World Health Organization [24]. The visual provides a summary of global drivers of heat and a list of heat hazards, including increasing frequency and intensity of heatwaves; rising average temperatures; solar radiation, humidity, and wind speed; and future climate scenarios. The framework details both the direct and indirect pathways through which these hazards might impact maternal, fetal, newborn, and child health, including different physiological mechanisms, as well as personal, community, and service-level social and economic impacts. The framework considers not only a broad and detailed range of possible health outcomes, but also vulnerability factors which might exacerbate risk, including compound events, biological, geographical, socio-political, and socio-economic factors. The High Horizons framework does not include abortion as a potential outcome of heat.

The Chersich, et al. framework (2022) divides the impacts of high ambient temperatures into three broader categories: pathophysiological or direct impacts, indirect impacts via infectious disease, and healthcare system stressors and resulting access problems [25]. Included outcomes are limited to adverse maternal and newborn health and therefore do not include pregnancy termination.

The framework designed by Bekkar, et al. (2023) similarly provides an overview of the perinatal heat-health burden in the shape of a pyramid, where the bottom represents less severe but more prevalent outcomes and the top represents more severe but less common outcomes [28]. Heat-related health outcomes shown in the graphic include “subtle” health impacts, including dehydration, preterm contractions, or epigenetic changes; labor and delivery triage and emergency visits, including preterm labor and heat-related illness; impacts with lifelong sequelae, including disabilities from prematurity; and newborn mortality or severe maternal

morbidity. Neither the framework nor the paper reference pregnancy termination as an outcome.

The fourth framework in this category, from Qian, et al. (2023), like the Ishikuro framework, presents empirical data following a specific historical exposure [26]. More specifically, the authors examine pregnancy health outcomes following exposure to temperature extremes at the 2nd, 5th, 10th, 90th, 95th and 98th percentiles of temperatures recorded in Beijing throughout the study in 2018. Also, like the Ishikuro framework, this model is limited exclusively to hypertensive disorders of pregnancy (HDP). As elective pregnancy termination does not fall within the range of HDPs, it is not included in the visual.

### **Existing research on pregnancy termination following natural disasters and environmental hazards**

While little research specifically investigates induced abortion as an outcome of natural disasters, several studies find linkages between natural disasters and interruptions to SRH service delivery, decreased contraceptive use, and increased SGBV. Research also suggests a link between natural disasters and increased unintended and unwanted pregnancies, which are more likely to result in abortion than intended and wanted pregnancies. Additional research explores the attitudes of survivors of natural disasters towards pregnancy and child-bearing, as well as the impact of natural disasters and environmental hazards on essential medicines for maternal healthcare. We identified 26 studies from our additional targeted searches. We present characteristics of these studies in [Table 3](#).

Five studies investigated service disruptions during and following natural disasters. A narrative synthesis of the impact of natural disasters in low- and middle-income countries revealed that unwanted pregnancies were associated with a lack of service availability, including abortion services [9]. Similarly, a facility assessment in Bangladesh following flooding found decreased access to menstrual regulation (menstrual regulation is a program in Bangladesh that restores a woman's menstruation 10–12 weeks after a missed period, without the use of a pregnancy test) and post-abortion care for individuals experiencing complications [58]. A study following the 2009 Sumatra Earthquake in Indonesia found delays in service delivery, with only 60% of SRH services returned to normal within two weeks after the disaster [42]. Another study revealed that individuals requiring abortion services were burdened by temporary clinic closures, abortion funds running out of money, and their own financial restraints following Hurricane Harvey in the United States [39]. In Zambia, seasonal flooding decreased overall maternal healthcare access and increased travel times among individuals still able to access services [50]. These delays can affect access to necessary SRH services to prevent unintended pregnancies and address unwanted pregnancies.

Decreased contraceptive access is an outcome of disaster-related service disruptions and can cause increased unintended and/or unwanted pregnancies. Following an earthquake in Indonesia, individuals with trouble accessing contraception experienced a significant increase in unintended pregnancies [42]. After the 2010 Haiti earthquake, there was decreased contraceptive coverage [43], increased current pregnancy [43], increased unwanted pregnancies [43,53], and pregnancies were more likely to have a shorter interpregnancy interval [53]. A study in Iran revealed decreased contraceptive coverage in the year of an earthquake compared to the preceding and succeeding years [44]. Another Iranian study identified decreased use of long-acting contraceptive methods, increased use of short-acting methods, and increased unintended pregnancy among individuals who had trouble accessing contraception after a different earthquake [40]. Lack of contraceptive coverage following Hurricane Ike in the United States led to a significant increase in unprotected sex [51]. In the United States after Hurricane Katrina, 17% of participants in a study needed health care but could not access

**Table 3. Studies exploring pregnancy termination and other related maternal health outcomes following natural disasters and environmental hazards.**

Title	Authors (year)	Geography	Purpose of research article	Pregnancy termination or other related maternal outcome(s) identified
A Report On The Reproductive Health Of Women After The Massive 2008 Wenchuan Earthquake	Liu, et al. (2010) [38]	China	To evaluate the reproductive health of women in the aftermath of the 2008 Richter scale 8.0 Wenchuan earthquake in China	<ul style="list-style-type: none"> <li>• Desire to delay or limit pregnancies</li> <li>• Desire to terminate pregnancies</li> </ul>
Another Disaster: Access To Abortion After Hurricane Harvey	Leyser-Whalen, et al. (2020) [39]	United States	To understand the intersection of abortion and disaster	<ul style="list-style-type: none"> <li>• Lack of finances and clinic closures affecting abortion access</li> </ul>
Change In Contraceptive Methods Following The Yogyakarta Earthquake And Its Association With The Prevalence Of Unplanned Pregnancy	Hapsari, et al. (2009) [40]	Indonesia	To examine access to contraception and change in contraceptive methods before and after the disaster in the Bantul area, and to evaluate the prevalence of unplanned pregnancy	<ul style="list-style-type: none"> <li>• Long-acting contraceptive use decreased, while use of short-acting methods increased</li> <li>• Unintended pregnancy increased among individuals facing barriers to family planning services</li> </ul>
Climate Shocks Constrain Human Fertility In Indonesia	Sellers & Gray (2019) [41]	Global	To understand changes in fertility decision-making, contraceptive use, and births after climate shocks from 1993–2015	<ul style="list-style-type: none"> <li>• Desire to delay or limit pregnancies</li> <li>• Increased and decreased births, dependent on the climate shock</li> <li>• Increased or decreased family planning use, dependent on the climate shock</li> </ul>
Effect Of The September 2009 Sumatra Earthquake On Reproductive Health Services And MDG 5 In The City Of Padang, Indonesia	Djafri, et al. (2015) [42]	Indonesia	To examine the effect of the September 2009 Sumatra earthquake on availability and accessibility of reproductive health services and its possible impact on local Millennium Development Goals	<ul style="list-style-type: none"> <li>• Delay in resumption of normal sexual and reproductive health services</li> <li>• Increased unintended pregnancies</li> </ul>
Effects Of The 2010 Haiti Earthquake On Women's Reproductive Health	Behrman & Weitzman (2016) [43]	Haiti	To explore the effects of the 2010 Haiti earthquake on women's reproductive health, using geocoded data from the 2005 and 2012 Haiti Demographic and Health Surveys	<ul style="list-style-type: none"> <li>• Decreased contraceptive use</li> <li>• Increased current pregnancies</li> <li>• Increased unwanted pregnancies</li> </ul>
Evaluation Of Reproductive Health Indicators In Women Affected By East Azarbaijan Earthquake On August 2012	Bahmanjanbeh, et al. (2016) [44]	Iran	To identify the indicators of reproductive health in the women affected by the East Azarbaijan earthquake in August 2012	<ul style="list-style-type: none"> <li>• Decreased contraceptive use</li> </ul>
Extreme Events And Gender-Based Violence: A Mixed-Methods Systematic Review	Robin van Daalen, et al. (2022) [45]	Global	To investigate the linkage between extreme weather and climate events and gender-based violence	<ul style="list-style-type: none"> <li>• Increased gender-based violence</li> </ul>
Experiences Of Violence And Abuse Among Internally Displaced Adolescent Girls Following A Natural Disaster	Sloand, et al. (2017) [46]	Haiti	To describe the physical, psychological, and sexual violence among internally displaced adolescent girls following the 2010 Haiti earthquake and related risk factors, health concerns and cultural norms	<ul style="list-style-type: none"> <li>• Increased physical and sexual abuse</li> </ul>
Gender And Disaster: The Impact Of Natural Disasters On Violence Against Women In Nepal	Bradley, et al. (2023) [47]	Nepal	To examine the impact of natural disasters on violence against women during the post-disaster reconstruction phases of the 2015 earthquake and the 2017 floods	<ul style="list-style-type: none"> <li>• Increased sexual- and gender-based violence</li> </ul>
Heat Wave And The Risk Of Intimate Partner Violence	Sanz-Barbero, et al. (2018) [48]	Spain	To explore the effect of heatwaves on the risk of intimate partner violence	<ul style="list-style-type: none"> <li>• Increased intimate partner violence</li> </ul>
Impact Of The Great East Japan Earthquake On Spontaneous Abortion And Induced Abortion: A Population-Based Cross-Sectional And Longitudinal Study In The Fukushima Prefecture Based On The Census Survey Of The Fukushima Maternity Care Facility And Vital Statistics	Inoue, et al. (2023) [49]	Japan	To investigate the impact of the Great East Japan Earthquake in the Fukushima Prefecture on spontaneous and induced abortions with regard to seasonal variability	<ul style="list-style-type: none"> <li>• Increased pregnancy termination</li> </ul>
Impacts Of Seasonal Flooding On Geographical Access To Maternal Healthcare In The Barotse Floodplain, Zambia	Mroz, et al. (2023) [50]	Zambia	To assess flood impact on women's walking access to maternal services and vehicular emergency referrals for a monthly basis between October 2017 and October 2018	<ul style="list-style-type: none"> <li>• Decreased maternal health care access</li> <li>• Longer travel times to maternal health care</li> </ul>

(Continued)

Table 3. (Continued)

Title	Authors (year)	Geography	Purpose of research article	Pregnancy termination or other related maternal outcome(s) identified
Investigating the Linkages Between Pregnancy Outcomes and Climate in sub-Saharan Africa	Davenport, et al. (2020) [36]	Africa	To understand relationships between pregnancy outcomes and climate	<ul style="list-style-type: none"> <li>Increased pregnancy termination and miscarriage</li> </ul>
Natural And Social Disasters: Racial Inequality In Access To Contraceptives After Hurricane Ike	Leyser-Whalen, et al. (2011) [51]	United States	To examine access to various types of birth control in a large sample of women from diverse backgrounds following Hurricane Ike, which made landfall on September 13, 2008, on the upper Texas Gulf Coast	<ul style="list-style-type: none"> <li>Decreased contraceptive use</li> <li>Increased unprotected sex</li> </ul>
Physically And Sexually Violent Experiences Of Reproductive-Aged Women Displaced By Hurricane Katrina	Picardo, et al. (2010) [52]	United States	To measure the frequency of physical and sexual abuse in a sample of reproductive aged women displaced by Hurricane Katrina and compare those experiences to previous year	<ul style="list-style-type: none"> <li>Similar levels of sexual- and gender-based violence</li> </ul>
Reproductive And Birth Outcomes In Haiti Before And After The 2010 Earthquake	Harville & Do (2016) [53]	Haiti	To examine the relationship between exposure to the 2010 Haiti earthquake and pregnancy wantedness, interpregnancy interval, and birth weight	<ul style="list-style-type: none"> <li>Increased unintended pregnancies</li> <li>Decreased interpregnancy interval</li> </ul>
Stability of Misoprostol Tablets Collected in Malawi and Rwanda: Importance of Intact Primary Packaging	Hagen, et al. (2020) [54]	Malawi, Rwanda	To investigate misoprostol tablet stability in temperature extremes when the packaging is damaged	<ul style="list-style-type: none"> <li>Decreased effectiveness of maternal health medication</li> </ul>
The Effect of Ambient Temperature Shocks During Conception and Early Pregnancy on Later Life Outcomes	Wilde, et al. (2017) [37]	Africa	To learn about whether increases in ambient temperatures lead to better educational and health outcomes for adults	<ul style="list-style-type: none"> <li>Decreased pregnancy termination and miscarriage</li> </ul>
The Effect Of An Earthquake Experienced During Pregnancy On Maternal Health And Birth Outcomes	Amarpoor Mesrkanlou, et al. (2022) [55]	Iran	To evaluate maternal health in pregnancy and birth outcomes between pre- and post-Varzaghan earthquake	<ul style="list-style-type: none"> <li>Increased pregnancy termination</li> </ul>
The Effect Of The Hurricane Katrina Disaster On Sexual Behavior And Access To Reproductive Care For Young Women In New Orleans	Kissinger, et al. (2007) [56]	United States	To describe changes in sexual behavior and access to reproductive care pre- and post-rapid displacement among a cohort of young women receiving family planning services before displacement	<ul style="list-style-type: none"> <li>Decreased health care access</li> <li>Decreased contraceptive use</li> <li>Increased unintended pregnancies</li> </ul>
The Impact Of Extreme Weather Events On Fertility Preference And Gender Preference In Bangladesh	Haq (2023) [57]	Bangladesh	To examine how different types of extreme weather events affect vulnerable people's decisions to have children or to prefer children of a certain gender	<ul style="list-style-type: none"> <li>Differences in fertility and gender preferences across extreme weather event-prone areas</li> </ul>
The Impact Of Natural Disasters And Epidemics On Sexual And Reproductive Health In Low- And Middle-Income Countries: A Narrative Synthesis	Loewen, et al. (2022) [9]	Low- and middle-income countries	To describe how natural disasters and epidemics affect multiple dimensions of SRH service delivery and outcomes, and to identify potential approaches to facilitate resumption of services	<ul style="list-style-type: none"> <li>Increased unintended pregnancies due to lack of service availability</li> </ul>
Understanding Reproductive Health Challenges During A Flood: Insights From Belkuchi Upazila, Bangladesh	Ray-Bennett, et al. (2019) [58]	Bangladesh	To study the challenges related to menstrual regulation and post-abortion care at both the facility and community levels, and the care-seeking patterns of pregnant women during the 2016 flood in Belkuchi, Bangladesh	<ul style="list-style-type: none"> <li>Decreased access to pregnancy termination</li> <li>Decreased access to post-abortion care</li> </ul>
Violence Against Women And Natural Disasters: Findings From Post-Tsunami Sri Lanka	Fisher (2010) [59]	Sri Lanka	To examine the types of violence occurring throughout the disaster's emergency and later phases, and whether overall levels of violence increased following a tsunami in Sri Lanka	<ul style="list-style-type: none"> <li>Increased sexual- and gender-based violence</li> </ul>
Women In Natural Disasters: A Case Study From Southern Coastal Region Of Bangladesh	Alam & Rahman (2014) [60]	Bangladesh	To explore women's preparedness, risk and loss, cultural and conditional behavior, adaptability, and recovery capacity from the natural disasters	<ul style="list-style-type: none"> <li>Increased risk of sexual harassment</li> </ul>

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it, 40% had not used birth control, and 4% experienced an unintended pregnancy as a result of lack of access to care; compared with baseline, after the hurricane, women were less likely to have attended family planning services or to have used family planning [56]. A global study of the effect of climate shocks on health found mixed results: delays in monsoon season resulting in desire for childbearing and declines in family planning use, whereas abnormally high temperatures led farm-dwelling women to increase their use of family planning and researchers observed fewer births in this population [41]. Access to contraception is only one of the vital services affected by climate-related disasters.

We identified seven studies that explored SGBV following climate-related disasters. A systematic review including 41 studies that looked at SGBV after storms, floods, droughts, heatwaves, and wildfires found evidence to support increases in one or more forms of SGBV following these events [45]. In Bangladesh, there was an increased risk of sexual harassment for pregnant and adolescent girls in cyclone shelters, including “unwelcome body touch,... unwanted physical contact, taking advantage of physical proximity of a young girl, look intently at female organs” [60]. In another study, which was conducted following an earthquake in Haiti, adolescents reported experiencing increased physical and sexual abuse, when controlling for age and education [46]. Qualitative results from post-tsunami Sri Lanka revealed that women and girls experienced rape and sexual abuse in the immediate tsunami aftermath, and that the violence continued even after the disaster emergency phase [59]. Another long term study in Nepal found that women experienced increased sexual violence in the years following a flood and earthquake [47]. A longitudinal time series study in Spain found that risk of intimate partner violence increased three days after heatwaves, police reports of intimate partner violence increased one day after heatwaves, and help line calls increased five days after heatwaves [48]. Another study did not find increased sexual violence among individuals reporting their abuse within relationships before and after Hurricane Katrina in the United States [52]. While these studies did not report on abortion decision-making, they reveal the consequences of climate-related disasters for adverse reproductive health outcomes related to SGBV.

One study explored fertility and gender preferences of individuals in three extreme weather event-prone areas (flood, drought, cyclone) [57]. Individuals in flood-prone and drought-prone areas were significantly more likely to want more children, but similar proportions of individuals in each group had a gender preference for future children.

Three studies reported on the impact of natural disasters on abortion-seeking attitudes and practices. In a study exploring family planning attitudes following the 2008 Wenchuan Earthquake in China, 89.4% of women surveyed said that they would abandon or delay plans for pregnancy due to the disaster; 61.7% reported that they would terminate a pregnancy, predominantly due to the bad environment (53.3%) and economic conditions (33.3%) following the disaster [38]. In Iran, the rate of abortion increased significantly, from 10.54% to 17.11%, immediately preceding and following an earthquake [55]. In the one year following the 2011 Great East Japan Earthquake, researchers found that the rate of induced abortion, and not miscarriage, increased [49]. Limited access to SRH services and poor environmental, financial, and social conditions following natural disasters appear to be influencing factors leading to increased induced abortion.

We found two studies that assess the association between temperature exposure and abortion, though neither of the referenced datasets differentiate between spontaneous and induced abortion. One study used data for fifteen countries from the African Demographic and Health Survey and reported an increased risk of early pregnancy loss, including both induced and spontaneous abortions, when pregnant women were exposed to temperatures >100°F during

the first trimester [36]. In contrast, other researchers found that high temperature exposure reduces the probability that a pregnancy ends in a spontaneous or induced termination [37].

A final study reported on the effect of heat on misoprostol, which is used to induce labor, manage miscarriage, treat postpartum hemorrhage, and singly or in combination with mifepristone as medication abortion [54]. This study, conducted in Malawi and Rwanda, found that high temperature extremes (>40°C) reduced the stability of misoprostol when stored outside the original packaging. Not only do natural disasters and environmental hazards reduce access to health services, they also impact the reliability of an essential medicine.

### **The Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO) conceptual framework**

None of the frameworks in our scoping review include pregnancy termination as an outcome of natural disasters, though we found evidence to support its inclusion due to the ways in which disasters and hazards affect health outcomes, health systems operations, and health decision-making. Given the importance of conceptual frameworks in informing disaster and emergency response planning – and the allocation of resources in these responses – we propose a new conceptual framework, Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO), that considers all possible maternal outcomes of natural disasters and environmental hazards, including pregnancy termination (see Fig 2). Our framework builds on Harville, et al.'s work (2021) [23], which was included in our scoping review.

The framework begins with the occurrence of a natural disaster or environmental hazard and points toward both short- and long-term effects. These effects both impact and are impacted by the context in which the disaster occurs and are influenced by the mediators presented in our figure. Mediators of natural disasters on maternal morbidity and mortality include healthcare availability, healthcare service access, stress and mental health, pre-existing health conditions, relationship/partner and other social dynamics, and behaviors of the affected individuals. Healthcare access is broad, but specifically includes access to sexual and reproductive health services, including family planning and contraception, clinical management of rape, and safe and post- abortion care.

Like the Harville, et al. framework (2021) [23], the NEMO framework includes both short- and long-term effects that are affected by various mediators. Short-term effects of natural disasters include changes to fertility desires, physical and psychological trauma, environmental exposures, and evacuation. Fertility desires may include the wantedness of existing pregnancies or preference to become pregnant or avoid pregnancy. Physical and psychological trauma and environmental exposures may act directly or indirectly upon current pregnancies and psychological trauma may also impact decision-making around health service-seeking behaviors. Evacuation from one's home may present additional barriers to health services or put them at increased risk of violence. Long-term effects include changes to fertility desires, physical and psychological trauma, economic impacts, and relocation and/or displacement. While changes to fertility desires, physical and psychological trauma, and relocation act similarly to the short-term effects of natural disasters, economic impacts as a long-term effect of natural disasters may affect decision-making relation to reproduction and health care seeking behaviors, hinder service access due to cost, or prevent access to other important resources before, during, and after pregnancy, such as contraceptives or adequate nutrition.

The interaction of these effects and mediators can lead to the following maternal health outcomes: unwanted pregnancy, injury, pregnancy complications, miscarriage or stillbirth, and pregnancy termination. For example, if an individual becomes pregnant, desires an abortion, and does not have access to health services in the wake of a disaster, they may induce a pregnancy termination in less safe conditions, which may lead to complications, including

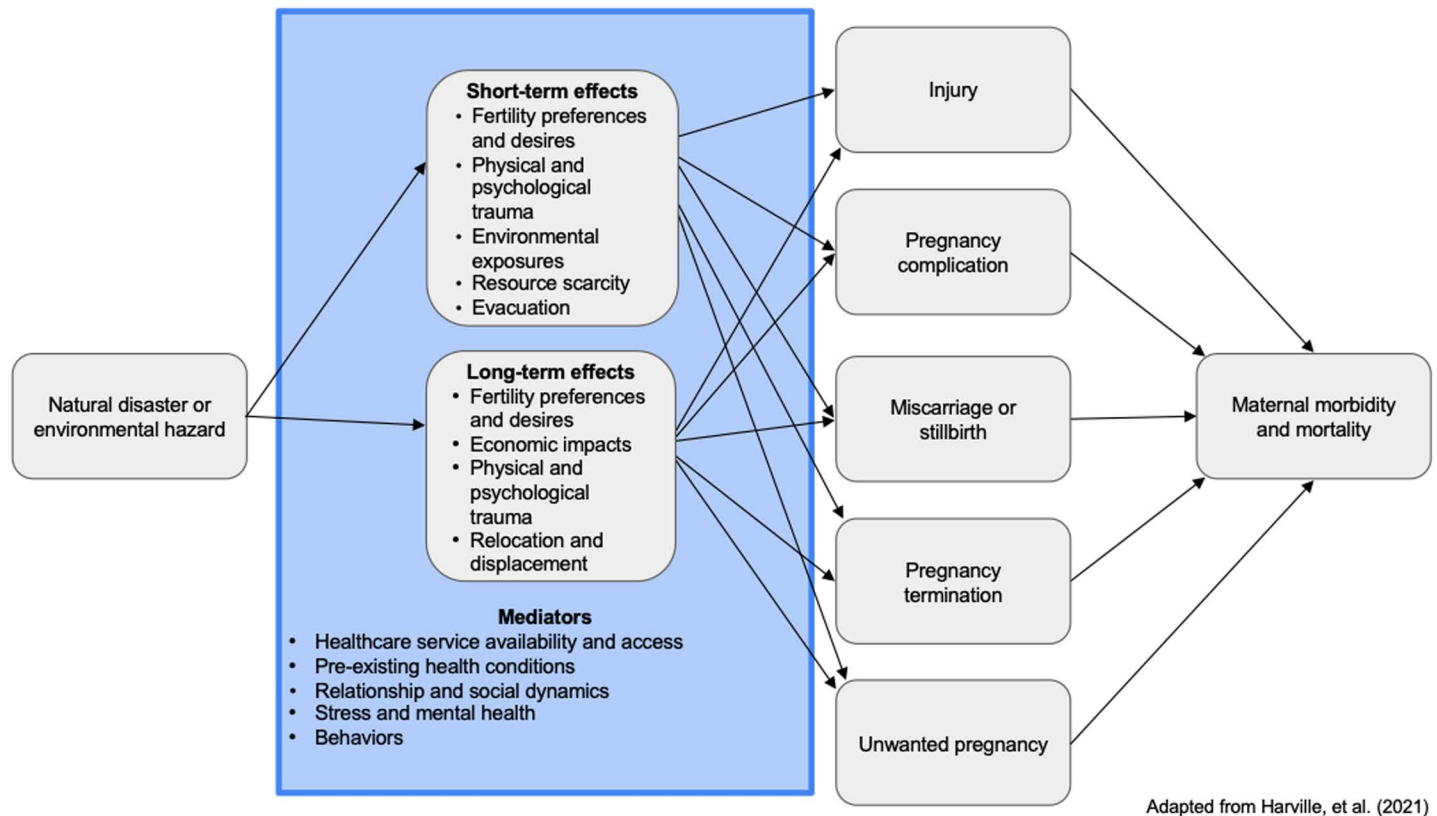


Fig 2. Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO) conceptual framework.

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maternal morbidity or mortality. Likewise, if a pregnant individual experiences physical trauma but decides not to seek out care, this could lead to pregnancy complications, and ultimately, maternal morbidity or mortality. Ultimately, any of these outcomes can result in maternal morbidity or mortality.

## Discussion

None of the frameworks identified in our scoping review include changes in fertility preferences or pregnancy termination as possible outcomes of natural disaster and environmental hazards. While none of these frameworks are wrong, they could benefit from broader inclusivity. Ultimately, the purpose of a conceptual framework is to identify key variables and relationships, inform future research, and provide the context in which to interpret results and act upon recommendations [61,62]. As such, conceptual frameworks should aim to make their audience consider all possibilities. Partial or inaccurate frameworks invite opportunities for missteps, omissions, and misinterpretation – all of which can hinder effective emergency response planning.

In this manuscript, we present a new conceptual framework of maternal health outcomes following natural disasters, the Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO) framework. To our knowledge, NEMO is the first framework of its kind to include pregnancy termination as an outcome by taking into account potential changes in fertility desires during and after a natural disaster. We explicitly include pregnancy

termination for both individuals who were pregnant before a disaster whose fertility intentions have since changed, and individuals who become pregnant following a disaster.

The findings of this study and resulting framework have important implications for pregnant women, global health practitioners, humanitarian response actors, and governments. Induced abortion is a common outcome of pregnancy: of the 121 million unintended pregnancies each year, approximately 61% end in pregnancy termination [63]. Despite this, services offered by humanitarian response actors often fail to include induced abortion due to complex legal landscapes. This study serves as a reminder to both public health officials and practitioners of the importance of availability of abortion as a service for individuals in these situations. Though these services may be difficult to implement in many country contexts, there are resources available to assist with ensuring individuals affected by disaster receive the medical care they need, including pregnancy termination [64,65]. Induced abortion is recognized as a necessary service for individuals in humanitarian crises and should be a top priority in implementation [65].

We hope that the NEMO framework will be used to support this implementation by promoting more comprehensive disaster planning. Various international humanitarian response guidelines acknowledge the importance of protecting maternal and women's health in the context of disasters. The World Health Organization's Health Emergency and Disaster Risk Management Framework, for example, explicitly identifies maternal and neonatal health as a priority for intervention before, during, and after emergencies [17]; the United Nations' Sendai Framework (2015–2030) considers maternal health as a basic health service that must be protected to “save lives, prevent and reduce losses, and ensure effective recovery and rehabilitation” after disasters [18]; and the United Nations Office for Disaster Risk Reduction, in its 2022–2025 strategic framework, calls for the integration of human rights and gender equality into disaster risk reduction [66]. The NEMO framework can help address these priorities in context by providing evidence and identification of women's needs, along with a comprehensive model to ensure humanitarian response actors both consider and seek to provide the necessary care for all possible disaster outcomes, including induced abortion, in order to protect women's right to health.

Ultimately, this study calls attention to the need for and encourages additional research to better understand reproductive health outcomes following natural disasters, especially as they relate to fertility- and abortion-decision making and practices. Our scoping review identified only three items published in the past twenty years indexed to PubMed and CINAHL that explore abortion-decision making or practices as an outcome of natural disasters [38,49,55]. While this is sufficient evidence to support the inclusion of pregnancy termination in conceptual frameworks exploring reproductive health outcomes of natural disasters, it is not expansive enough to accurately capture the specific needs of individuals experiencing unintended and/or unwanted pregnancies in the wake of disasters, or individuals who were pregnant before the disaster and whose fertility intentions have since changed.

There are important limitations of our study. We conducted a scoping review of two databases to identify the range of conceptual frameworks that already exist on our topic of interest. Given this decision, it is possible that we missed studies that would have been captured in a systematic review that included a wider range of databases. Similarly, we did not conduct an exhaustive literature search on abortion outcomes following natural disasters. Instead, we conducted a specific search to identify English language studies published in the past twenty years to determine whether there exists enough evidence to support the inclusion of induced abortion as an outcome in these frameworks. Lastly, although our focus is primarily on maternal health outcomes, we acknowledge the critical linkages with newborn and infant health outcomes. Despite these limitations, this is the first conceptual framework that includes induced abortion as an outcome of natural disasters.



## Conclusion

There is sufficient evidence to support the inclusion of pregnancy termination as a possible outcome of some natural disasters. We look forward to more research about the associations between these exposures and fertility- and abortion-decision making that will continue to build the evidence base. Failure to consider pregnancy termination as a possible outcome of these events may be detrimental to the health of women and others capable of pregnancy who experience natural disasters – both those who are pregnant before disaster strikes and whose fertility intentions may change, as well as those who become or will become pregnant following a disaster. Given the increasing frequency and intensity of both climate hazards and natural disasters, global health practitioners, governments, and other humanitarian response actors require comprehensive conceptual frameworks to ensure that no one is left behind in disaster response: we hope that the Natural disasters, Environmental hazards, and Maternal Outcomes (NEMO) framework will contribute to making that a reality.

## Supporting information

**S1 Data. Data referenced in NEMO framework manuscript.**  
(DOCX)

**S1 Checklist. PRISMA checklist.**  
(DOCX)

## Author contributions

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**Supervision:** Ndola Prata.

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**Visualization:** Cara Schulte, Blake Erhardt-Ohren.

**Writing – original draft:** Cara Schulte, Blake Erhardt-Ohren.

**Writing – review & editing:** Cara Schulte, Blake Erhardt-Ohren, Ndola Prata.

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