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Impacts of climate change on food security and resulting perinatal health impacts

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ABSTRACT

Climate change's impact on global food security is a pressing concern with profound consequences. Climate change disrupts the global food system through a number of mechanisms including extreme weather events, rising food prices, and compromised food quality. In this article, we explore the effect of climate change on food security and the resulting health impacts of poor nutrition on pregnant women and infants in the perinatal period. Inadequate nutrition during pregnancy raises the risk of vitamin deficiencies, obstetric complications, maternal mortality, and infant malnutrition. Climate change exacerbates these challenges and perpetuates intergenerational cycles of poor nutrition. Addressing these issues requires traditional approaches to combating the climate impacts on general food security as well as specific approaches to bridge the food security gender gap. Empowering women as key stakeholders is crucial for overcoming the complex barriers to food insecurity caused by climate change, as well as protecting the well-being of vulnerable populations during the perinatal period.

Introduction

The consequences of a changing climate affect many parts of people's lives, from their jobs, to their homes, to their health. One of the most profound ways in which people will be affected is through what they eat every day. Due to the interconnectivity of the global food system, no geographic area or social class will be spared as extreme weather events disrupt supply chains, food prices rise from local and global pressures, and food quality and safety are compromised from contaminated crops and water. A recent meta-analysis on projections of global food security for the years 2010-2050 found that when taking climate change into consideration, global food demand will change by +30 % to +62 % and populations at risk for hunger will change from −91 % to +30 %.[1] These wide ranges reflect the uncertainty of the response of the global food system and local and international governments. Food security is already high with, "29.3 % of the world's population, 2.3 billion people, were moderately or severely food insecure in 2021" and 3.1 billion people were unable to afford a healthy diet.[2]

Food security is crucial for individuals across all stages of life, serving as a cornerstone of overall health and economic productivity; however, it assumes even greater significance for women during the heightened nutritional needs associated with pregnancy and infants during the perinatal period. For pregnant women, inadequate energy intake and nutritional diversity increases the risk of traditional disorders of vitamin deficiencies and is implicated in the development of obstetric complications including infection, hypertensive disorders, gestational diabetes, preterm delivery, postpartum hemorrhage, and death.[3] Severely undernourished women have higher rates of maternal mortality, miscarriage, stillbirths and having newborns who are underweight. Currently it is estimated that worldwide 10 % of people of childbearing age are underweight, 30 % suffer from anemia and 66 % suffer from vitamin deficiencies.[4]

For the developing newborn, maternal malnutrition has direct and long-lasting impacts on their growth and development. According to UNICEF: "Poor nutrition is passed down through generations (and) about half of children under 2 with stunting become stunted during pregnancy and the first six months of life."[4] There are also long term consequences for infants such as: increased risk of adult chronic diseases,[5,6] autism spectrum disorders, ADHD, impaired cognitive development, missed school[7] and lower average lifetime earnings.[7,8] Animal

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models have suggested these consequences may be partially explained by epigenetic and metabolic changes to the fetus in utero. Globally, 1 in 3 children is malnourished in its most visible forms: stunting, wasting, and overweight and 1 in 2 children suffer from invisible essential nutrient deficiencies termed "hidden hunger."[8] While food security is closely related to socioeconomic status, food insecure communities exist within all countries.

In the following sections, we will explore how a changing climate impacts food systems and food security, as well as how these impact the unique nutritional needs of pregnant women and of infants in the perinatal period.

Climate change impact on global food security

Climate change affects food systems, which encompass the entire cycle of "production, aggregation, processing, distribution, consumption, and disposal of food products," in multiple ways[9]. Disruptions in any aspect of the system can have substantial repercussions on food security (Table 1). For instance, extreme weather events such as hurricanes, floods, droughts, and wildfires can destroy crops before they are harvested and destroy essential infrastructure[10] while rising temperatures contribute to pollen sterility and water stress, resulting in decreased yields.[11] Wheat, rice, and maize are all sensitive to rises in temperature[12] and currently supply half of global calories.[13] While yields may increase in some geographies due to longer growing seasons, the overall impact is negative. Changes in temperature and water availability impact the territories of plant pathogens, exposing crops to novel infections[14] and in some cases, selecting for more virulent strains. For insect pathogens, warmer temperatures can decrease the percentage of the population that dies each winter and increase the number of generations born.[15] High temperatures suppress the plant's immune response, leading to increased vulnerability.[14] Weeds become more prolific, competing for resources with the main crop and requiring more intense chemical or mechanical intervention.[14,15]

The loss of production is not limited to agriculture. Fishing is impacted as rising water temperatures and acidity decrease the amount of oxygen dissolved in water and impact fish habitats.[16] Increasing acidity damages coral reefs that serve as anchors to food chains[16] and extreme weather events damage fishing boats and nets.[17] Saltwater intrusion from sea level rise contaminates freshwater fish habitats and decreases the amount of usable farmland and drinkable water.[16,18] In terms of livestock, drought decreases the food and water available for animals resulting in poor herd health[10,19,20] and high mortality rates. For communities that rely on hunting, health and availability of animals can be impacted by drought, heat, and other extreme events. The loss of sea ice is particularly problematic in the arctic circle where sufficient ice coverage is needed for the hunting of whales and walruses.[21]

In addition to food lost during production, climate change also increases food loss during storage and transfer to communities. Heat and flooding increase spoilage rates in areas without adequate facilities during post-harvest processing and storage.[22] Extreme weather events damage roads, ports, markets, and other infrastructure, impacting transportation of goods and preventing food from reaching local communities. If the roads to market are impassable, families will not be able to get the food they need, even if it is available in the market.[18]

Crop failure can have cascading effects where the loss in production in previous seasons will cause some farmers to leave farming while others may choose not to plant their fields for fear of losing the little resources, they had left for uncertain gain.[10,23]

Climate change also impacts a household's ability to afford food. If there is a decrease in the amount of food in the market, food prices will increase, either in general or for specific food items.[18,24,25] For producers of food- farmers, fishers and hunters- decreased food production results in loss of jobs and income.[18,25,26] For consumers of food, higher food prices result in less diverse and nutritious diets, leading to various forms of malnutrition.[27] Decreases in the ability to afford food after extreme weather events are well documented[18,26] and high food prices have greater impact on food consumption in lower income countries and in low-resource households within both high and low income countries.

In situations where food availability is limited or prices are high, families employ various coping mechanisms to mitigate the risk of food insecurity. These mechanisms include choosing less expensive food, skipping meals, eating less food at meals, diversifying income streams, planting more crops, selling household assets, and prioritizing certain members of the family to eat.[25,28] When families switch to cheaper alternatives, the alternatives are often less diverse and less nutritious.[24,29] This can result in micronutrient deficiencies even when there are sufficient macronutrients.

Finally, apart from the amount and quality of food that households can afford or is available, climate change also has impacts on the body's ability to process nutrients. Contaminated water and food from flooding, drought, and damaged infrastructure can increase the spread of diarrheal infectious diseases, affecting nutrient absorption. Other climate sensitive vector borne diseases, such as malaria and dengue,[30] have complex bidirectional relationships with nutrition where malnourished and infected pregnant women and children generally, but not always, have worse outcomes, and the infection itself can cause malnutrition.

Table 1
Impacts of climate change on food security.

Climate change impacts on food security	
Climate drivers	Heatwaves
	Drought
	Flooding
	Sea levels rise
	Loss of seasonal ice
	Cyclones/hurricanes
	Increased CO2
	Loss of biodiversity
Intermediate impacts	Crop destruction or decreased yields
	Livestock/fishery disruptions
	Hunting disruption
	Disruption in transportation/storage of food
	Water supply contamination
Outcomes	Decreased food availability
	Decreased food quality
	Increased food prices
Family coping mechanisms	Selling household assets
	Diversifying income
	Decreasing number of meals
	Decreasing portion sizes
	Prioritizing nutrition of certain family members
When coping mechanisms are inadequate, food insecurity occurs	

Food quality and micronutrients

Studies have shown ambient CO2 in the air impacts the growth rates and nutritional density of foods. At higher rates of CO2, some types of crops can utilize the extra carbon to increase growth, however, when the nutrient content of these crops are measured, some have been found to have decreased concentrations of protein, iron, zinc, vitamin A, and B vitamins (folate, thiamine, and riboflavin), and calcium. The impact of CO2 on plant physiology is related to the type of photosynthesis- C3 vs C4- the plant utilizes. C3 crops include rice, wheat, barley, and potatoes. These plants show increased yields under high levels of CO2 (averaging an increase of 19 % for all crops, 34 % for hybrid rice and up to 27 % for potato tubers),[31] however, these yields are potentially diminished or completely erased under conditions of increased temperature.[31] C4 crops, like maize, show less growth response to elevated CO2 levels.[31]

While yields may increase under higher levels of CO2, the nutrient content has been shown to decrease. While the percentage decrease varies based on the specific micronutrient, macronutrient and plant studied, a recent modeling study suggests the gross impact of increased ambient CO2 could result in global decreases of 19·5 % for protein, 14·4

% for iron, and 14·6 % for zinc.[32] For specific health impacts, it is suggested by 2050, an additional 148.4 million people (1.6 %) of the world's population may be at risk of protein deficiency;[33] 38 million could be at risk of zinc deficiency;[34] 132 million people for folate, 67 million for thiamin, and 40 million for riboflavin.[35] Another study looking at current diets and rates of anemia found that 1.4 billion children (ages 1–5) and women of childbearing age are currently living in countries where rates of anemia are >20 %, putting them at high risk of worsening anemia from the projected decreases in dietary iron availability (estimated at 2 % decrease) under high CO2 levels.[36]

In addition to worsening the micronutrient content of crops, changes in the climate could also affect the availability of micronutrients in other ways. A recent review on the impact of climate change on pollinators suggests that populations will be adversely affected.[37] Pollinators are essential for the cultivation of fruits and vegetables, nuts and seeds and declines in their populations are estimated to have significant impacts on the global availability of vitamin A, vitamin C and folate, though with significant regional variability.[38] Declines in fishing will also have a significant impact on the availability of zinc, vitamin A and iron.[12]

Pregnant people's nutritional status and the gender gap in food insecurity

The health of a pregnant person is closely related to their nutritional status preconception. While food security for all populations is threatened by climate change, women face additional challenges (Table 2a). The gender gap in nutrition is significant. According to the UN World Food Program, 60 % of people who are food insecure are females and in two-thirds of countries, women are more likely than men to report food insecurity.[39] The reason for this is multifaceted. In a study using data from 146 countries examining factors contributing to the gender gap in food insecurity, the authors found that the majority of the gap was explained by women's relatively lower incomes, educational attainment, access to social support networks, and rates of employment.[40] For social reasons women may be prevented from participating in labor outside the house, holding certain jobs, owning land, or inheriting wealth, making it impossible for them to engage in coping mechanisms to prevent food insecurity. This has significant impacts on female-headed households, which have been found to experience higher levels of food insecurity after extreme events than male-headed households.[23] Finally, when families are forced to decrease food intake, women are more affected as they are often the last to eat and eat the poorest quality food.[23]

In addition to the direct impacts on nutrition through food availability, quality and affordability, climate change creates challenging food environments which disproportionately impact women. If families are forced to migrate or live in camps due to weather related displacement, cooking, breastfeeding, and maintaining dietary diversity all become more difficult. Crisis settings have been found to exacerbate the gender gap in food insecurity between women and men.[41] When food prices are high, rates of early marriage may increase which impact future earning potential for girls and decrease the age of first child. This has cascading effects on women's immediate and future food insecurity. Thus, as the climate undergoes changes that exacerbate the overall food security of populations, women experience the initial and most pronounced repercussions. See Fig. 1. for a specific case study demonstrating the compounding impacts of drought on perinatal health.

Table 2a
Impacts of food insecurity on pregnant and lactating women.

Direct	Indirect
Undernutrition or obesity	Increased risk of exposure to violence
Micronutrient deficiencies	Increased risk of mental health conditions
Decreased diet diversity	Loss of family support due to migration
Adverse pregnancy outcomes	Increased risk of early marriage
Increased risk of infection	
Small or large for gestational age infants	

Underweight

When pregnant women are underweight, they have worse pregnancy outcomes for themselves and their newborns.[42] A study in Nepal of 22000 women found that upper arm circumference was inversely associated with all-cause maternal mortality up to 42 days post-partum.[19] Studies performed during famine conditions suggest that undernutrition in the periconceptual period increases the risk for preterm delivery and undernutrition in the third trimester leads to small for gestational age (SGA) infants.[43] Similarly, a study of a Gambian population that experiences seasonal malnutrition found similar results with the highest levels of SGA infants born at the end of the "hungry season" before the harvest and the high rates of preterm delivery nine months after this period, suggesting that poor nutritional status in the periconceptual period had a negative impact.[44] Macronutrient deficiency leads to immune system dysfunction which can increase the risk of infection for pregnant women. In areas of high malaria prevalence, pregnant women who are malnourished are more likely to contract malaria[45] and their children have worse outcomes as maternal infection impacts placental development and health.

Micronutrient deficiencies

When pregnant people have poor dietary diversity, they are at risk of developing deficiencies in specific micronutrients. Micronutrient deficiencies impact the health of the pregnant person and of the developing fetus (Table 3). Additionally, they have been linked to the pathophysiology of specific obstetric complications. Climate change will exacerbate the burden of disease from micronutrient deficiencies by limiting access to diverse food groups and by decreasing the nutritional quality of staple foods.

For example, recent evidence suggests several vitamin deficiencies (D, C, E and calcium) may be linked to the development of preeclampsia. Hypertensive disorders of pregnancy develop during the pregnancy or postpartum period, and cause severe morbidity, disability, and death. In fact, nearly 10 % of all maternal deaths in Africa and Asia[46] and 6.3 % in the United States[47] are attributed to hypertensive disorders . While hypertensive disorders have long been linked to maternal chronic hypertension, obesity, and diabetes, insufficient intake of vitamins D, C, E, and calcium may contribute to disease burden.[46] Daily intake of the adequate amount of these vitamins requires access to a diverse diet of fruits and vegetables or fortified food which, as discussed earlier, can be challenging when food prices are high, extreme events limit access to food, or the nutritional content of food is decreased through exposure to elevated CO2 or ozone levels.[48,49] Vitamin D deficiency is also correlated with small for gestational age infants and the risk of spontaneous abortion.[49]

Postpartum hemorrhage, blood loss of greater than 500 mL within 24 hours of birth, remains the leading cause of maternal morbidity and mortality across the globe, and is impacted by iron deficiency.[50] Optimizing maternal nutrition prior to delivery and after addresses physiologic and pathologic maternal anemia and aids in a more effective recovery. Iron deficiency anemia contributes to postpartum hemorrhage, maternal fatigue, and inadequate breast milk production. While the causes of anemia are multifactorial, anemia can be mitigated by adequate consumption of iron rich foods as well as folate and vitamin C, both of which are necessary to produce functioning red blood cells. Unfortunately, modeling studies have predicted rises in CO2 will decrease both the folate and iron content in rice grains.[51] These changes in the nutritional content of a staple food will put hundreds of millions of people at risk of folate and iron deficiency, especially those in low- and middle-income countries who depend on rice as a majority of their diet.

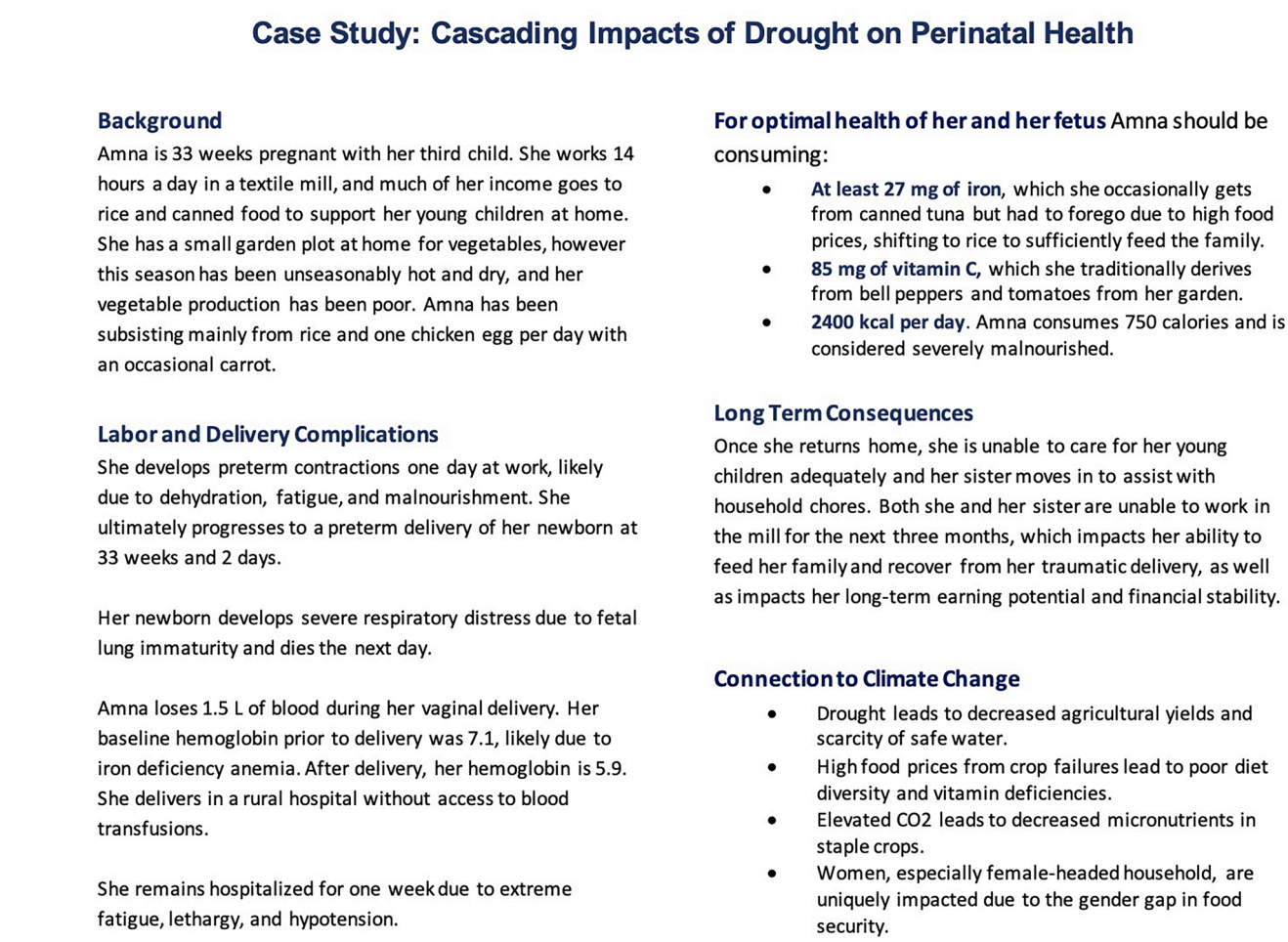

Fig. 1. The cascading impacts of drought on perinatal health: a sample case study. This figure illustrates the potential consequences of drought on maternal nutritional, birth complications, newborn outcomes, and long-term health and financial security.

Obesity

Globally the rates of pregnant women who are overweight or obese are increasing, even in areas traditionally associated with hunger and starvation. In 2014, it was estimated that 38.9 billion pregnancies were affected by obesity.[52] The global increase in obesity is multifactorial and beyond the scope of this article, however there is a well-recognized paradox for the coexistence of food insecurity and obesity,[53] particularly for women. The mechanisms behind this paradox are still under review, with the overall quality of evidence being poor. However, studies suggest that fresh, nutritionally diverse foods may be prohibitively expensive and lead to the consumption of energy dense, processed foods due to lower cost, greater accessibility, and longer shelf life.[54]

Obesity in pregnancy is associated with an increased risk of pregnancy loss, congenital abnormalities, cardiac dysfunction, sleep apnea, nonalcoholic fatty liver disease, gestational diabetes mellitus, preeclampsia, and stillbirth.[5,42] Intrapartum complications include risk of cesarean delivery, development of gestational diabetes, failed trial of labor, endometritis, wound rupture or dehiscence, and venous thrombosis. Postpartum complications include obesity later in life outside of pregnancy, early termination of breastfeeding, postpartum anemia, and depression.

The link between climate change and obesity is being investigated and the direct impact on future rates of this multifactorial disease is unknown. Poor air quality and heat may decrease rates of physical activity and contribute to more sedentary behavior.[55,56] Higher food prices make cheaper, processed foods, which are calorie dense and known to be obesogenic, more attractive.[27,56] Heat and air pollution have also been associated with higher levels of gestational diabetes,[57] a risk factor and possible sequelae of obesity.

Impact of climate change on infant nutrition in the perinatal period

For infants in the perinatal period, nutrition is primarily determined by maternal health status and neonatal breastmilk or formula supply (Table 2b). As discussed previously, climate change has significant impacts on maternal nutrition; these impacts can lead to SGA infants, preterm delivery, and specific micronutrient deficiencies in the infant (Table 3). Iron deficiency leads to anemia, folate deficiency can lead to neural tube defects, vitamin A deficiency leads to night blindness and chronic lung disease, and zinc deficiency can lead to dysfunctions of the infant's immune system and poor wound healing.[58] The expected global burden of these diseases due to climate change effects is still in the early

Table 2b
Impacts of food insecurity during the perinatal period on infants.

Direct	Indirect
Stunting/wasting	Decreased lifetime earnings
Suboptimal brain development	Missed days of school
Increased susceptibility to infections Increased risk of death	Increased risk of obesity, heart disease, diabetes, osteoporosis later in life

Table 3
Pregnancy and neonatal complications from micronutrient and macronutrient deficiencies and the compounding impact of climate change.

Impact of micro- and macro-level deficiencies			
Pregnancy complications			
	Nutrition connection	Other risk factors	Effect of climate change
Hypertensive disorders of pregnancy (gestational hypertension, preeclampsia)	Vitamins C, E Calcium Vitamin D	Obesity Chronic hypertension	Poor crop yield of fruits and vegetables containing vitamins C and E Droughts leading to livestock deaths, poor access to dairy due to lack of refrigeration, increased heat Inadequate sun exposure due to natural disasters, poor access to foods fortified with vitamin D
Postpartum hemorrhage	Iron, Folate, Vitamin C	Anemia Intraamniotic infection Gestational hypertensive disorders	Inadequate intake of iron rich foods, which include protein sources and vegetables
Gestational diabetes (GDM)	Obesity	Environmental exposures Extreme high and low temperatures	Climate change increases air pollution and leads to extreme highs and lows in ambient temperature, all of which have been associated with GDM Climate change limits access to safe drinking water; water with arsenic, cadmium, persistent organic pollutants, and bisphenol A linked to gestational diabetes Increased consumption of processed foods, poor diet diversity
Preterm delivery	Under or overweight	Gestational hypertensive disorders Gestational diabete Stress Environmental exposures Maternal infection	Food insecurity leads to malnourishment or limited access to over-processed foods Climate change increases exposure to air pollution, nitrates and arsenic in drinking water
Neonatal complications			
Small for gestational age	-Maternal undernutrition, especially in the third trimester	Hypertensive disorders of pregnancy Maternal smoking Low socioeconomic status of the mother	Food insecurity leading to maternal malnutrition. Exposure to climate sensitive diseases ex. malaria.
Late term fetal demise/ stillborn	Gestational diabetes,	Intraamniotic infection Environmental	Climate change leads to food insecurity, which

Table 3 (*continued*)

Impact of micro- and macro-level deficiencies			
Pregnancy complications			
	Nutrition connection	Other risk factors	Effect of climate change
	maternal low or high BMI	exposures Hypertensive disorders	results in poor nutrition of pregnant person
Necrotizing enterocolitis	Formula feeding Maternal diabetes	Preterm delivery SGA Intraamniotic infection	Food insecurity leading to poor breast milk production and excessive formula feeding
Large for gestational age	Maternal obesity, excessive pregnancy weight gain	Maternal gestational diabetes	Climate change leads to food insecurity, which results in overeating of over-processed foods
Neonatal infections	Maternal malnutrition, zinc deficiency	Pollution exposure	Environmental pollutants and exposures due to climate change
Childhood wasting and stunting	Maternal malnutrition		Food insecurity leading to maternal malnutrition and challenging breastfeeding.

stages; however, one modeling study investigating the impact of vitamin B deficiencies alone estimated an additional annual loss of 27,900 life years and 260 deaths from neural tube deficits.[35]

Conditions caused by a changing climate can also affect a women's ability to breastfeed. While exclusive breastfeeding is recommended due to the well-established benefits of breastfeeding on the health and development of the young child, currently, only 2 out of 5 children worldwide are exclusively breastfed in the first six months of life. Mothers worldwide face a range of barriers to initiating and maintaining breastfeeding. Lactating women require an estimated 640 additional kcal and a range of micronutrients to maintain their own nutrition.[59] Climate change impacts on food prices and food availability make it more difficult to reach these nutritional needs. In households that depend on the lactating woman to contribute to the financial security of the home, food insecure mothers face a difficult decision. While the money they save on formula could be used for other necessities, breastfeeding can have negative effects on maternal earnings by keeping women out of the workforce. Where guaranteed paid maternity leave is not available, these challenges are particularly pronounced among women who have low incomes, are unmarried or young, and those from marginalized communities.

When climate change intensifies water scarcity and contamination, infants may be exposed to contaminated water and face an increased risk of diarrheal diseases leading to dehydration and malnutrition. This risk is especially high for formula fed infants. When extreme weather events cause migration, dividends of breastfeeding are particularly high due to lack of access to clean water, healthcare, or breastmilk substitutes.[60] Fortunately, studies have shown infants are adequately hydrated and receive sufficient nutrition with breast milk even during periods of hot weather.[61] See Fig. 2 for a discussion of breastfeeding in emergencies.[62–65]

Summary and recommendations

A changing climate affects food security now and will continue to affect food security into the future through complex and interconnected ways. Women and infants in the perinatal period have increased

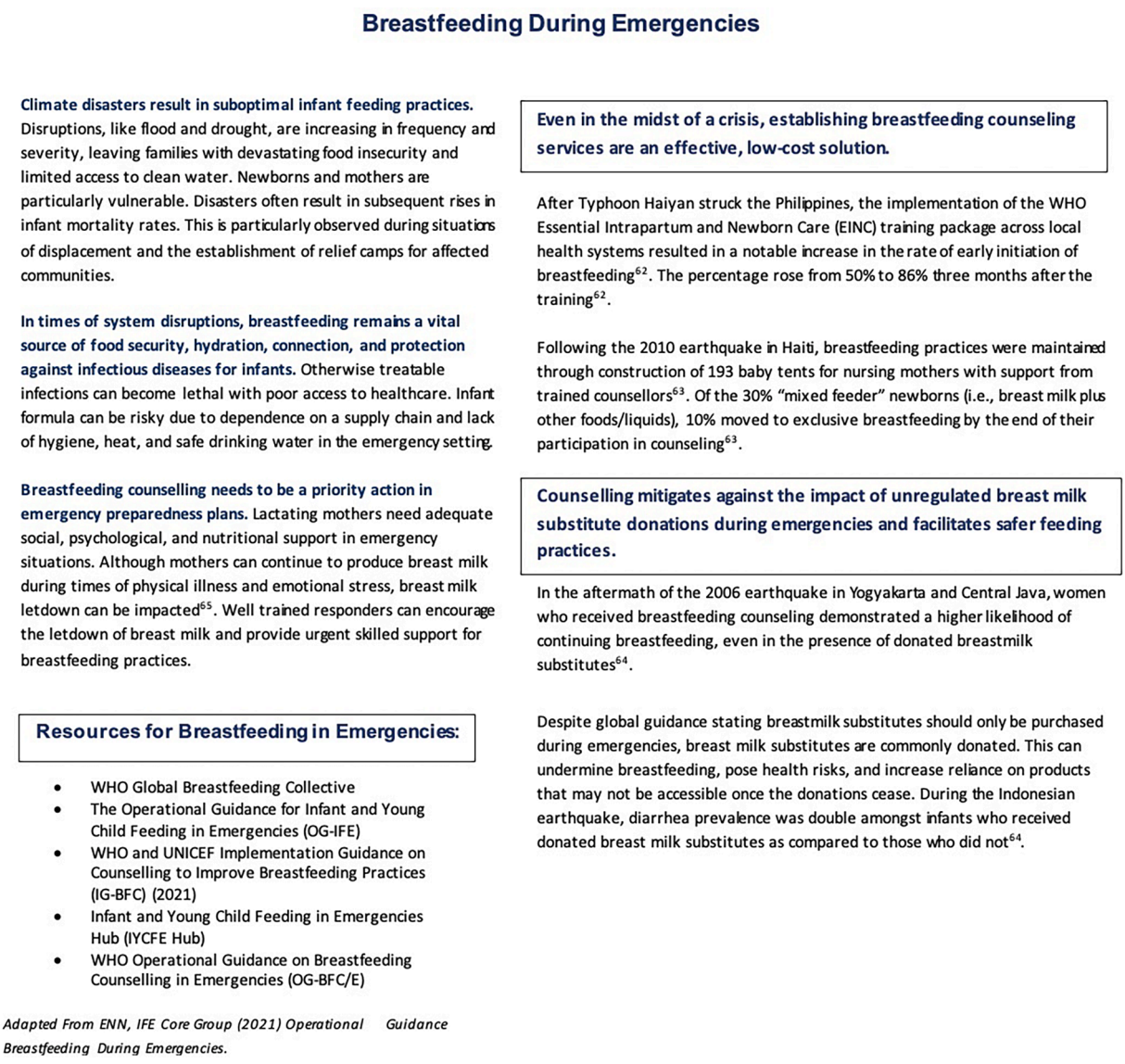

Fig. 2. The benefits of breastfeeding counseling and initiation during climate crises and humanitarian emergencies. Fig. 2 highlights the positive impact on maternal and newborn health and nutrition when breastfeeding counseling is incorporated into emergency response plans.

nutritional needs which make them uniquely vulnerable to food insecurity and nutritional deficiencies (Table 2). The consequences impact health and productivity in both the short and long term. Fortunately, there are strategies that can help mitigate the impact of climate change on food security during the perinatal period. First, enhancing overall food security entails reducing greenhouse gas emissions, diversifying crop production, implementing early warning systems for food producers, promoting drought and flood-tolerant crops, and expanding access to social safety.

Second, the gender gap in food security needs to be addressed to improve baseline nutrition in women of reproductive age. This includes investing in women's education, decreasing legal barriers to owning and inheriting land and other assets, preventing early marriage, increasing access to employment opportunities, and providing sufficient food aid in times of crisis so that women are not forced to sacrifice their own health for the good of the family. For pregnant and lactating women, food security can be increased through access to a diverse diet and to fortified foods. Increased household and community knowledge about the nutritional needs of pregnant women and the impact on the developing fetus may help households make better choices about food allocation in times of scarcity. For lactating mothers, it is essential to provide paid maternal and paternal leave, breastfeeding breaks, and create a supportive environment with adequate childcare facilities and lactation spaces. For infants, exclusive breastfeeding is the best nutrition, however in cases where formula is needed, ensuring access to clean water, sufficient amounts of safe and affordable formula, as well as sterilized bottles is key.

We must acknowledge the critical role of women in perinatal nutrition and climate change as vital agents of change who possess valuable knowledge, caregiving abilities, and educational capacities. Interventions that start with engaging women as key stakeholders will be more culturally acceptable and better able to account for the complex and interconnected barriers to food insecurity that arise from climate change. This will improve the health of pregnant and lactating people, infants, and subsequent generations to come.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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