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The Nexus Between Climate Variability and Undernutrition: A Systematic Review

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ABSTRACT

Undernutrition is a confront to the health and output of the populace. It is viewed as one of the five leading contrary health impacts of climate variability and is defined as different measures of nutritional status. We aimed to assess the scientific evidence base for the impact of climate variability on childhood undernutrition (particularly wasting and underweight) in low- and middle-income countries. A systematic review was conducted to identify the peer-reviewed and gray full-text studies in English with no limits for the year of publication and study design. This review covers only published studies from four databases (PubMed, Scopus, Web of Science, and Science Direct). The risk of bias was assessed using the ROVBIS tool in individual studies. The PRISMA Statement checklist for systematic reviews was referred for this review process. A significant correlation between climate variables, temperature, rainfall, and drought, and at least one undernutrition parameter in 19 out of 22 studies was observed in this systematic review. In addition, we note that crop yield, maternal education, nutritional status of mothers, wealth status at the household level, and individual levels also play substantial roles in mediating the nutritional impacts. The findings of our analysis imply that exposure to climate variables may be linked to an increased risk of undernutrition both during and for several years following climate events. This may imply that undernutrition is never caused by temperature, precipitation, drought, or other weather-related factors alone but rather that undernutrition is triggered in children who are already at risk.

INTRODUCTION

Children's bodies are delicate and highly susceptible to climatic changes, so any impairment they suffer during these formative years may have long-term effects (Bennett & Friel 2014). Undernutrition, defined as various measures of nutritional status, is a threat to the population's health and productivity and is considered one of the five main adverse health effects of climate variability (Phalkey et al. 2015, Madan et al. 2018). Climate change is expected to increase the current global burden of child malnutrition across climate variables, including temperature, precipitation, and humidity (Belesova et al. 2019). In the developing world, child undernutrition poses a serious health risk, impeding children's long-term growth and development (Amir et al. 2022). It is widely acknowledged that human development at the individual, societal, and global levels depends on children receiving adequate nutrition up until the age of five. It has also been shown that chronic malnutrition during early life can permanently damage a child's physical and mental development (McMahon & Gray 2021).

Undernutrition during early childhood can permanently impair an individual's well-being and socioeconomic achievement throughout their life, and it may increase children's risk of other morbidities and mortality (Pelletier et al. 1995). Here, our goal is to determine the undernutrition status in low- and middle-income countries due to climatic variables. Previous studies have not determined the undernutrition status among children under five in low- and middle-income countries. Children under the age of five who are exposed to climate variability without protection may have long-term health and social consequences (Alderman et al. 2006, Currie & Vogl 2013, Maccini & Yang 2009).

After considering these factors, we qualify our prediction that above-average temperatures and precipitation will have the greatest negative impact on childhood nutrition. Finally, we consider the strength and direction of climate effects as a research question. We examine the respective effects of temperature, precipitation, and humidity inconsistencies on child wasting and underweight across a sample from 9 different countries and sub-Saharan countries in low and middle countries. Our findings add to the emerging literature on climate and nutrition. This study focuses on the six main climate variables: temperature, precipitation, humidity, cyclone, drought, and rainfall. Using extensive data sets, our systematic review investigated relationships between climate variability and childhood nutrition in low- and middle-income nations.

It is anticipated that variations in temperature, precipitation, humidity, and the secondary effects of similar environmental variations will have an impact on child malnutrition in several ways (Grace et al. 2012, Randell et al. 2020). Food security, availability, and accessibility in low- and middle-income communities that depend on rainfed agriculture can vary significantly between and within communities based on seasonal factors such as temperature and rainfall (Lieber et al. 2022, Niles et al. 2021). Given these circumstances, implementing healthy infant and young child feeding (IYCF) practices-such as exclusive breastfeeding and feeding beginning at 6-59 months-can be fatal for ensuring that kids receive the nutrition they need to grow and develop according to growth and development metrics (Shively 2017). Few studies have examined the effects of specific extreme climate variables on child nutrition; most of these studies have focused on low- and middle-income countries, which are the most vulnerable to climate variability. A family's ability to afford food may also be impacted by climate variability if there are differences in income that are not related to changes in crop yields or costs (Mueller et al. 2020). According to the Intergovernmental Panel on Climate Change, since 1970, average surface temperatures have risen by roughly 1.70 degrees Celsius per decade due to greenhouse gas emissions. By the year 2100, average surface temperatures worldwide are expected to have increased by 1.80^{o} Celsius to 4.00^{o} (IPCC 2007). In contrast to climate variability, which denotes naturally occurring variations in temperature and precipitation that occur over months to years, like the El Niño Southern Oscillation, climate change (McMichael & Kovats 2000, Ziervogel et al. 2006). The primary distinction between the two pertains to their temporal scales: climate variability usually transpires over periods ranging from months to years, whereas climate change transpires over decades to extended durations (Smit et al. 2000, Zhang & Huang 2012).

There is a knowledge gap and a lack of clarity regarding the relationship between climate variability and nutrition outcomes in children because the relationship between the two is not well understood and is frequently unclear (Macheka et al. 2022). Strategies for adapting to climate change should integrate nutrition security, giving special attention to those who are most at risk of undernutrition in childhood (Tirado et al. 2013, Crahay et al. 2010). By 2050, child undernutrition may increase by up to 20% as a result of decreased food production and declining nutritional quality, and 600 million more people will be hungry as a result of climate change (Field & Barros 2014).

In low- and middle-income nations with sufficient data available, we aimed to specify summary estimations of the status of underweight and wasting among children aged 6-59 months and investigate the effects of temperature, precipitation, and humidity on childhood undernutrition. The purpose of this systematic review article is to elucidate the main climatic variability that low- and middle-income countries face and how it may affect the nutrition of children. Risks resulting from temperature increases and extreme weather are taken into account. The methods currently in use to stop or lessen these effects are outlined, along with suggestions for future developments that could be crucial to enhancing the nutrition of children in low- and middle-income nations. A previous review primarily aimed at articles before the year 2015 examined the association between climate variability and childhood stunting and found variable associations (Chowdhury et al. 2020). Specially, this study found that extreme weather events and fluctuations in temperature and precipitation were associated with childhood underweight and wasting in 21 out of 22 studies.

In this paper, we evaluated published (peer-reviewed) data on database studies about climate variables in low- and middle-income countries (LMICs) regarding undernutrition among children under the age of five. The following research questions were the focus of the investigation:

What is the current status of climate variability-related undernutrition?

Which undernutrition parameters are most frequently employed in research?

What aspects of the climate variables affect the nutrition of children?

What is the relationship between undernutrition in children and climate variability?

MATERIALS AND METHODS

Literature Review Methodology

Eligibility and ineligibility criteria: Certain eligibility criteria were identified through the goal of choosing and incorporating only noteworthy studies for our topic of the systematic review acknowledged from the databases (Table 1).

Information source and search strategy: The systematic review took into account English language studies that were published between January 2014 and June 2023. We used Scopus, PubMed, Science Direct, and Web of Science to search the literature. In October 2023, a total of 276 publications from PubMed, 892 from Web of Science, 125 from Scopus, and 57 from Science Direct were found. These

Table 1: Eligibility and ineligibility criteria.

Eligibility Criteria	Ineligibility Criteria
EC1: Journal Articles	IC1: Proceedings of conference papers, books, book chapters, and other nonpeer-reviewed publications.
EC2: The study is written in English.	IC2: The study is not written in English.
EC3: The study is peer-reviewed.	IC3: The study is not peer-reviewed.
EC4: The study is not listed in another database.	IC4: The study is listed in another database.
EC5: The study was conducted in low and middle-income countries.	IC5: The study was not conducted in low and middle-income countries.
EC6: The study is related to environmental subjects.	IC6: The study is not related to environmental subjects
EC7: The gray full text of the study is available.	IC7: The full text of the study is not available
EC8: The study includes research or descriptions of climate variables and childhood undernutrition	IC8: The study only includes opinions about climate variability and childhood undernutrition
EC9: The study addresses the relationship between climate variability and undernutrition	IC9: The study does not address the relationship between climate variability and undernutrition, or it mention it just briefly
EC10: The study focused exclusively on wasting and underweight	IC10: The study focused exclusively on stunting

Table 2: Information source and search string with parameters.

Information Source	Search String and Parameters
PubMed	((((((“Climate Change”[Mesh]) AND “Malnutrition”[Mesh]) AND “Child”[Mesh])) OR “Extreme Weather”[Mesh]) AND (“Weather”[Mesh] OR “Extreme Hot Weather”[Mesh]) Document type: Article Language: English
Scopus	(ALL (“weather variability”) OR ALL (“climate change”) AND TITLE-ABS-KEY (“impact”) AND TITLE-ABS-KEY (“child nutrition”) OR ALL (“under-nutrition”) AND NOT TITLE-ABS-KEY (“maternal nutrition”)) AND PUBYEAR > 2005 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, “ar”)) Document type: Article Language: English
Web of Science	((((((ALL=(“weather events”)) OR TS=(climate variability)) AND TS=(child undernutrition)) AND TS=(impact)) OR TS=(malnutrition)) NOT TS=(mother)) Document type: Article Language: English
Science Direct	Term(s): “extreme weather events” OR “climate change” AND “child nutrition”; Document type: Article Language: English

four databases were chosen based on their widely recognized impact indices, which include peer-reviewed, scholarly literature published globally in a variety of scientific fields and arenas (Salisbury 2009).

Using Boolean operators (AND, OR, NOT) with simple operators using parenthesis in the search string, the search strategy was based on the use of fundamental concepts related to the study’s topic and research question (Khine & Langkulsen 2023). A search string was created following testing and a fast review of the syntax needed by each database (Table 2).

Data Collection and Selection Process

Following the initial literature searches, the titles and abstracts of each study were examined, and any potentially pertinent studies were further evaluated for eligibility. The study selection procedure is explained in great detail in the PRISMA flow diagram (Fig.1). We selected the pertinent articles based on the eligibility and ineligibility standards. Research that the titles and abstracts judged unnecessary were not included. After an independent review of the remaining studies, disputed studies were either included or excluded based on a consensus.

Twenty-two suitable journal articles from nine low- and middle-income countries, published over 9 years, were found by our search: four articles from Bangladesh, one from Brazil, three from Burkina Faso, four from Ethiopia, two from Ghana, one from Kenya, two from India, one from Nepal, two from Sub-Saharan Africa, one each from Ghana and Bangladesh, and one from Uganda. The included studies reported a total of 22 main outcomes related to undernutrition across 6 climate variables. The most common criteria used to characterize climate variability were temperature, rainfall, humidity, precipitation, cyclones, and drought. Significant undernutrition in children was found in 19 studies. Every study published results for children younger than 60 months.

Data Items (Outcomes)

Table 3: The examined undernutrition outcomes and their measurements.

Undernutrition Effects	Measurements	Acronym
Wasting	Weight-for-Height Z-scores Mid-upper arm circumference	WHZ MUAC
Underweight	Weight-for-age Z-scores	WAZ

Synthesis Methods

Data synthesis was done by two authors (NKC and KT) by using a synthesis format arranged in Microsoft Excel. The PRISMA Statement checklist for systematic reviews was referred for the review process (Page et al. 2021). The search results were combined, and duplicates were automatically eliminated before a second manual revision. The full-text review was left for the studies whose eligibility was questionable. The 92 chosen articles underwent full-text reviews, manual data synthesis, and matrix documentation by the two independent reviewers (N.KC and K.Techato). Differences were agreed upon and accepted.

We performed narrative synthesis into a matrix format: reference, first author name, year of publication, study period, sample size, age in months, geographical focus, data source, the status of undernutrition, parameters of undernutrition, climate variability, and the association between climate variability and undernutrition included in the models (Table 4).

RESULTS AND DISCUSSION

Study Selection

Initially, in our study, 1350 research papers were selected for study. After eliminating twelve redundant studies, 737 studies were eliminated based on their titles, and 320 abstracts were excluded. Since the criteria did not align with the study's goals, an additional 189 studies were eliminated. Out of the 92 papers that were left for the analysis, 41 papers did not align with the findings of this investigation, 24 papers did not align with the geographical context, and 5 systematic reviews were excluded. Following the removal of 70 papers altogether, 22 papers were chosen for this analysis, as

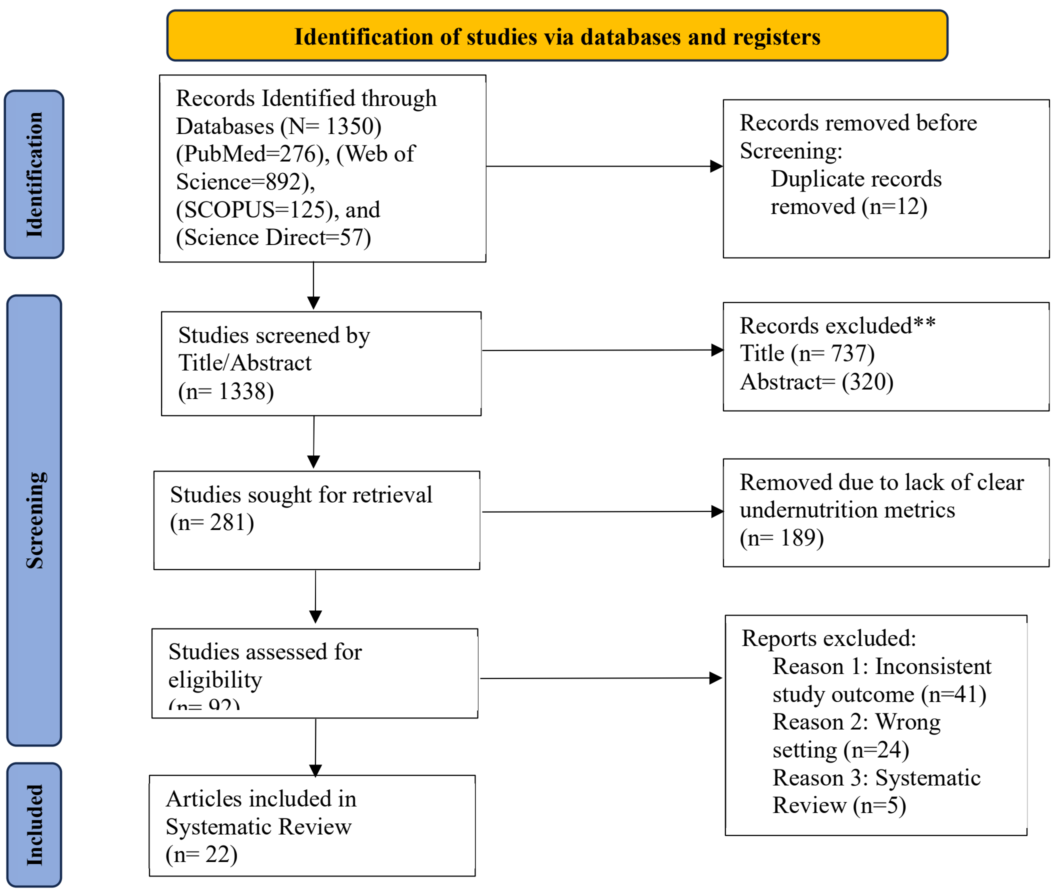

Fig. 1: PRISMA 2020 flow diagram for new systematic reviews, which included searches of databases and registers only.

depicted in Fig. 1. Four primary databases, PubMed, Scopus, Web of Science, and Science Direct, were used to finish it. The eligibility and ineligibility criteria were established before the selection of these papers.

Study Characteristics

In each study, the age category of children under the age of five and the sample size varied greatly, ranging from 0 to 60 months and 40 to over 200000, respectively. Three studies presented primary data analysis, only one study presented both primary and secondary data analysis, and the majority of the studies used secondary data. In this study, papers published from 2014 to 2023 were analyzed. Every article in this analysis originated in a low- or middle-income nation. Of the 22 papers that made up this analysis, 4 had longitudinal study designs, and 18 had cross-sectional study designs. Table 4 provides a summary of each study's key features.

Assessment of the Risk of Bias in Individual Studies

In individual studies, the ROVBIS tool was used to evaluate the risk of bias. We allocated the five domains according to each study's ROBVIS assessment. The bias resulting from the randomization process, deviations from intended interventions, missing outcomes, bias in outcome measurement, and bias in the selection of reported results were the five main domains (McGuinness & Higgins 2021). Every study received a score of "high," "low," or "some concerns." Each article received an inclusive ROBIS score, as suggested by the tool's guidelines. The possibility of bias in the studies' conclusions has been highlighted by an evaluation of their validity that was part of a Cochrane review.

The risk of bias in each included study has been evaluated by the Cochrane Collaboration, which has also compiled data by type of undernutrition in Fig. 2. This includes an explanation and an assessment for every entry in a "Risk of Bias," where each entry deals with a particular aspect of the research. Each entry is evaluated based on its response to the question; 'Yes' indicates a low risk of bias, 'No' indicates a high risk, and 'Unclear' indicates neither a lack of information nor some reservations about potential bias.

What is the current status of climate variability-related child undernutrition in low and middle-income countries?: Child undernutrition was observed in all of the selected low- and middle-income nations in this study. This study specifically addressed the undernutrition of 9 distinct low- and middle-income countries as well as Sub-Saharan low- and middle-income countries. The problem of undernutrition among children under the age of five has been observed in most countries as a result of climate variables. The rate of wasting has increased in Nepal as a result of the heavy rains. Due to the drought, the rate of waste in Kenya has increased by 20%. Long-term rainfall increased wasting by 4.5 percent in Uganda, while humidity increased underweight by 10.5 percent. According to a study conducted in Malawi, high temperatures are likely to increase the rate of wasting in children. A Brazilian longitudinal study found a 2.5 percent increase in undernutrition for every 1°C daily increase in temperature. Excessive rainfall over twelve months was associated with the problem of wasting in Ghana, whereas the same problem was observed in Bangladesh among older children. Both studies in the Sub-Saharan region confirmed that as temperatures rose, children's wasting problems worsened. Several studies on climate variables and undernutrition in Bangladesh have discovered that temperature, cyclones, humidity, and rainfall are primarily to blame for children wasting and being underweight. Malnutrition among children is a problem, according to a study conducted in many districts of India where the Climate Vulnerability Index is high. Three studies in Burkina Faso discovered that high temperatures, drought, and high rainfall

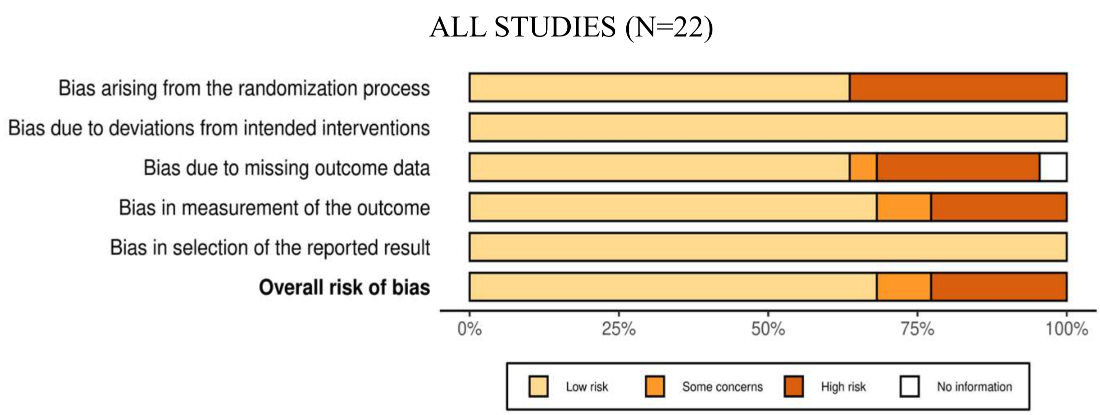

Fig. 2: The risk of bias in each included study.

Table 4: Summary of included studies

Articles	Author and Year of Publication	Study Period	Sample Size	Age in months	Geographic focus	Data Source	Study Design	Status of Undernutrition	Parameters of Undernutrition	Climate Variability	Association between climate variability and Undernutrition
1	Alfred, 2020	2015	5149	0-59	Malawi	Secondary	Cross-sectional	✓	Wasting	Rainfall, Temperature	✓
2	Ahsanuzzaman et al., 2020	2011	7861	0-59	Bangladesh	Secondary	Cross-sectional	✓	Wasting	Cyclone	✓
3	Kristine et al., 2017	1992-2012	44616	0-59	Burkina Faso	Secondary	Cross-sectional	✓	Underweight	Precipitation	✓
4	Hanson, 2021	2019-2020	40	0-59	Ghana	Primary	Cross-sectional	✓	Underweight	Rainfall	✓
5	Brian et al., 2020	1980-2019	400	0-59	Sub-Saharan	Secondary	Cross-sectional	✓	Wasting	Precipitation	✓
6	Shouro et al., 2020	1993-2010	NA	0-59	Burkina Faso	Secondary	Cross-sectional	✓	Wasting	Temperature, Precipitation	✓
7	Arbinda et al., 2020	2015-2016	NA	0-59	India	Secondary	Cross-sectional	✓	Wasting	Rainfall	✓
8	Arnout et al., 2017	2007-2011	4333	0-60	Bangladesh	Secondary	Cross-sectional	✓	Wasting	Rainfall	✓
9	Matthew et al., 2019	2011-2015	4617	0-60	Ghana & Bangladesh	Primary and Secondary	Cross-sectional	✓	Wasting	Rainfall	✓
10	Ahmed et al., 2022	2011-2020	19357	0-36	Bangladesh	Secondary	Cross-sectional	✓	Wasting	Temperature, Rainfall, Humidity	✓
11	Jan et al., 2017	2009-2013	3302	0-59	Kenya	Secondary	Cross-sectional	✓	Wasting	Drought	✓
12	Anna, 2021	2005-2016	21551	0-59	Ethiopia	Secondary	Cross-sectional	✓	Wasting	Drought	✗
13	Rachel et al., 2020	NA	190000	6-59	Sub-Saharan	Secondary	Cross-sectional	✓	Wasting	Temperature	✓
14	Ledlie et al., 2017	2011-2013	2659	6-59	Ethiopia	Secondary	Cross-sectional	✓	Wasting	Rainfall	✗
15	Chris, 2023	2013-2016	976	0-60	Uganda	Secondary	Longitudinal	✓	Underweight	Rainfall	✓

Table Cont....

Articles	Author and Year of Publication	Study Period	Sample Size	Age in months	Geographic focus	Data Source	Study Design	Status of Undernutrition	Parameters of Undernutrition	Climate Variability	Association between climate variability and Undernutrition
16	Bidhubhusan et al., 2021	2015-2016	243213	0-60	India	Secondary	Cross-sectional	✓	Wasting, Underweight	Rainfall, Temperature	✓
17	Isabel et al., 2021	2017-2019	1439	0-48	Burkina Faso	Secondary	Longitudinal	✓	Wasting	Rainfall	✓
18	Rongbin et al., 2019	2000-2015	31597	0-48	Brazil	Primary	Longitudinal	✓	Underweight	Temperature	✓
19	Hirvonen et al., 2020	2012-2016	3582	0-59	Ethiopia	Secondary	Cross-sectional	✓	Wasting	Drought	✗
20	Alice et al., 2023	2014-2015	1586	0-59	Bangladesh	Primary	Cross-sectional	✓	Wasting	Rainfall	✓
21	Sailesh et al., 2016	2001-2011	13682	0-60	Nepal	Secondary	Cross-sectional	✓	Wasting	Rainfall	✓
22	Seifu et al., 2014	1996-2004	145	0-59	Ethiopia	Secondary	Longitudinal	✓	Wasting, Underweight	Rainfall, Temperature	✓

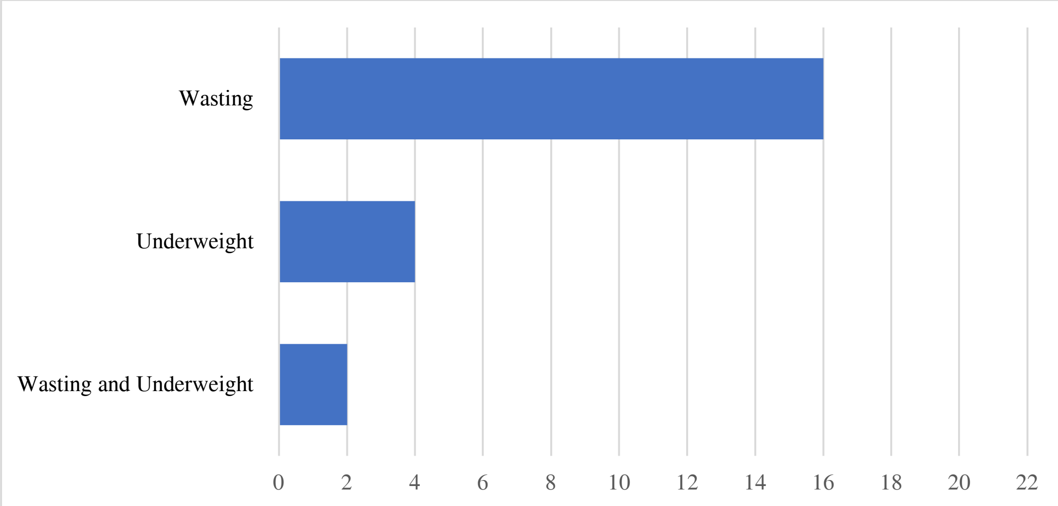

Fig. 3: Parameters of undernutrition observed in studies.

increased childhood wasting and underweight. Several cross-sectional and longitudinal studies in Ethiopia have found that high draft, high temperature, and high humidity are associated with an increased risk of childhood wasting and underweight.

Which undernutrition parameters are most frequently employed in research?: In this study, wasting was measured in 16 papers out of a total of 22 papers. Similarly, the problem of underweight has been measured in 4 papers, while wasting and underweight both have been observed in two papers (Fig. 3). Wasting and underweight, the main parameters of climate-related undernutrition in children, were studied from 1992 to 2019 using primary and secondary data on children aged 0 to 60 months. Although stunting is a key indicator of malnutrition, it was excluded because it did not fall within the scope of this study. In Malawi, Bangladesh, Burkina Faso, India, Ghana, Kenya, Ethiopia, Nepal, and Sub-Saharan Africa, wasting was measured. Burkina Faso, Uganda, Brazil, and Ghana all had underweight children. Both wasting and underweight were observed in Ethiopia and India.

What aspects of the climate variables affect the nutrition of children in low- and middle-income countries?: We identified six climate variables that specifically influence undernutrition in children under the age of five in this study. We primarily looked for temperature, rainfall, cyclone, precipitation, drought, and humidity climate variables in this study. Ghana, India, Bangladesh, Ethiopia, Uganda, Burkina Faso, and Nepal are among the nine countries where only rainfall has been studied. Similarly, rainfall and temperature were found in three different papers about the effect of two climate variables in India, Malawi, and Ethiopia. In Ethiopia and Kenya, we found 3 papers on the effects of drought on children's malnutrition. We observed in 2 papers that children from Sub-Saharan and Brazil have wasting and underweight problems due to the temperature. We noted in separate papers that the problem of wasting in children due to cyclones, wasting, and undernutrition due to precipitation has been affected in Bangladesh, Burkina Faso, and Sub-Saharan respectively. We observed the problem of wasting in children in a paper studied in the coastal region of Bangladesh by examining three climate variables; temperature, rainfall, and humidity. A study in Burkina Faso found that wasting is the major child undernutrition, using temperature and precipitation as climate impact variables.

What is the relationship between undernutrition in children and climate variability?: Nine studies that looked into the relationship between rainfall and undernutrition all found strong associations. It is well known that low crop production has an impact on children's nutritional status as a result of high rainfall. It showed that Bangladesh's high rainfall has led to an increase in the wasting rate (OR= 0.27, 95% CI: 0.17 - 0.44) among children between the ages of 0 and 59 months as compared with the low rainfall (OR=0.54, 95% CI: 0.35-0.83) (Wolfle & Channon 2023). Tiwari et al. (2017) confirm this result in Nepal that high rainfall (SD= 0.315, $P < 0.01$) had statistically significant impacts on wasting in comparison to normal rainfall (SD= 0.299, $P < 0.01$). Van Soesbergen et al. (2017) also discovered a significant correlation (OR= 0.27, $P < 0.05$) between rainfall and wasting, but they pointed out that the influence is caused by a collection of anomalies in the Normalized Difference Vegetation Index. A similar observation was reported from Kenya (Bauer & Mburu 2017). Isabel et al. noted that exposure of mothers to high rainfall may contribute to a decline in the weight-for-height scores (B= 0.032, 95% CI: 0.01-0.06, $P < 0.05$) among under 5 years children in Burkina Faso (Mank et al. 2021). Ledlie et al. found that shocks associated with rainfall had a statistically insignificant impact on undernutrition in children (SD= 0.56, $P > 0.05$). They state that there was a significant correlation between wasting and other factors like maternal education ($P < 0.05$) and the wealth index ($P < 0.05$) (Ledlie et al. 2018). Arbinda et al. India had the highest likelihood of wasted children (B = -1.5, $P < 0.001$) but not anemic ones (B = -0.21, $P > 0.05$) (Acharya & Das 2015). There was a significant correlation found between Ugandan children's long-term exposure to rainfall and both underweight and wasting (Boyd 2023). Matthew et al. assessed the standardized precipitation index (SPI) for excessive rainfall over a short time window of 12 months was associated with lower weight-for-height z scores (SD= 0.00236, $P < 0.05$) (Cooper et al. 2019). Stressful farming season and exposure to fluctuating rainfall cause mothers to be unable to feed their children, resulting in undernutrition (Nyantakyi 2021).

In eight of the twenty-two studies, the temperature was discussed. For underweight Ethiopian children aged 0-59 months, it was highly significant (R2 = -0.26). The authors found that, in addition to temperature, other significant determinants included livestock and rainfall during the growing season. However, they were unsure if the impact was due to per capita crop (Hagos et al. 2014). Using spatial autocorrelation to measure climate vulnerability rather than ambient temperature and rainfall. Bidhubushan et al. found the strongest evidence (AOR: 1.45, 95% CI: 1.30-1.61) for underweight children (Mahapatra et al. 2021). In Malawi, children who are exposed to higher temperatures have a higher likelihood of being wasted (B = 1.220, $P < 0.05$). According to the author, wasting was significantly correlated with additional factors like large family size, proximity to water, mother's BMI, and diarrhea (Ngwira 2020). According to Rachel et al.'s assessment of the monthly temperature variation, children's weight-for-height was significantly ($P < 0.001$) impacted by rising temperatures (25–300 C) in the survey month (Baker & Anttila 2020). Rongbin et al. found a strong positive correlation (OR= 1.025, 95% CI: 1.020-1.030, $P < 0.001$) between undernutrition and daily mean temperature increases of 10 C. They noted that the effect was as strong in males as in females (Xu et al. 2019). When Kristine et al. examined the relationship between child survival and the annual food crop productivity index, they found a strong correlation (Hazard Ratio= 2.73, 95% CI: 2.10-3.55) between underweight (Belesova et al. 2018). According to Brian et al., the prevalence of childhood wasting in Sub-Saharan Africa was 8.1 percentage points higher than the baseline average and was temperature-dependent (Thiede & Strube 2020). Ahmed et al. observed that children born at a higher temperature were significantly associated with 2.2 mm lower MUAC measures relative to the mean. They report that humidity was also strongly associated (P= < 0.05) with children wasting (Ahmed et al. 2022). Elizabeth reported that children in Burkina Faso experienced wasting when exposed to short-term weather shocks, particularly temperatures exceeding 260 degrees (Dasgupta & Robinson 2023).

However, Hirvonen et al. did not find that Ethiopian child wasting was influenced by drought. Rather, they identified the primary contributors as the head of the household's age, the availability of electricity, the availability of toilets, and the availability of safe water (Hirvonen et al. 2020). An analogous observation revealed no proof that Ethiopia's risk of child wasting is impacted by seasonal droughts (Dimitrova 2021).

One study out of 22 examined how undernutrition children are to cyclones. For children ages 0 to 12 months, the cyclone was positively significant for underweight and wasting ($P < 0.001$); however, this was not the case for children older than 12 months (Ahsanuzzaman & Islam 2020).

DISCUSSION

The results of our review confirm the hypothesis that undernutrition is caused by a complex network of interdependent and interconnected farming, environmental, socioeconomic, demographic, and health factors at the societal, family, and individual levels (Fig. 4). We observed that many of the mediating factors are sensitive to changes in climate variability. The UNICEF framework lists the following reasons for undernutrition in children: underlying causes (food insecurity, poor hygiene and sanitation practices, inadequate health and nutrition services), immediate causes (diseases and inadequate diet practices), and enabling causes (political, financial, and social actions) (UNICEF 2021).

In more than 85% of the 22 studies that made up the review, a significant correlation was found between undernutrition and one or more climate variables. To make any kind of inference, however, more or contradictory data on humidity, precipitation, drought, and cyclones were required. Rainfall and temperature were still frequently discussed factors.

Climate variables were most frequently associated with anthropometric measures (especially underweight and wasting) in children under five years old. Existing research

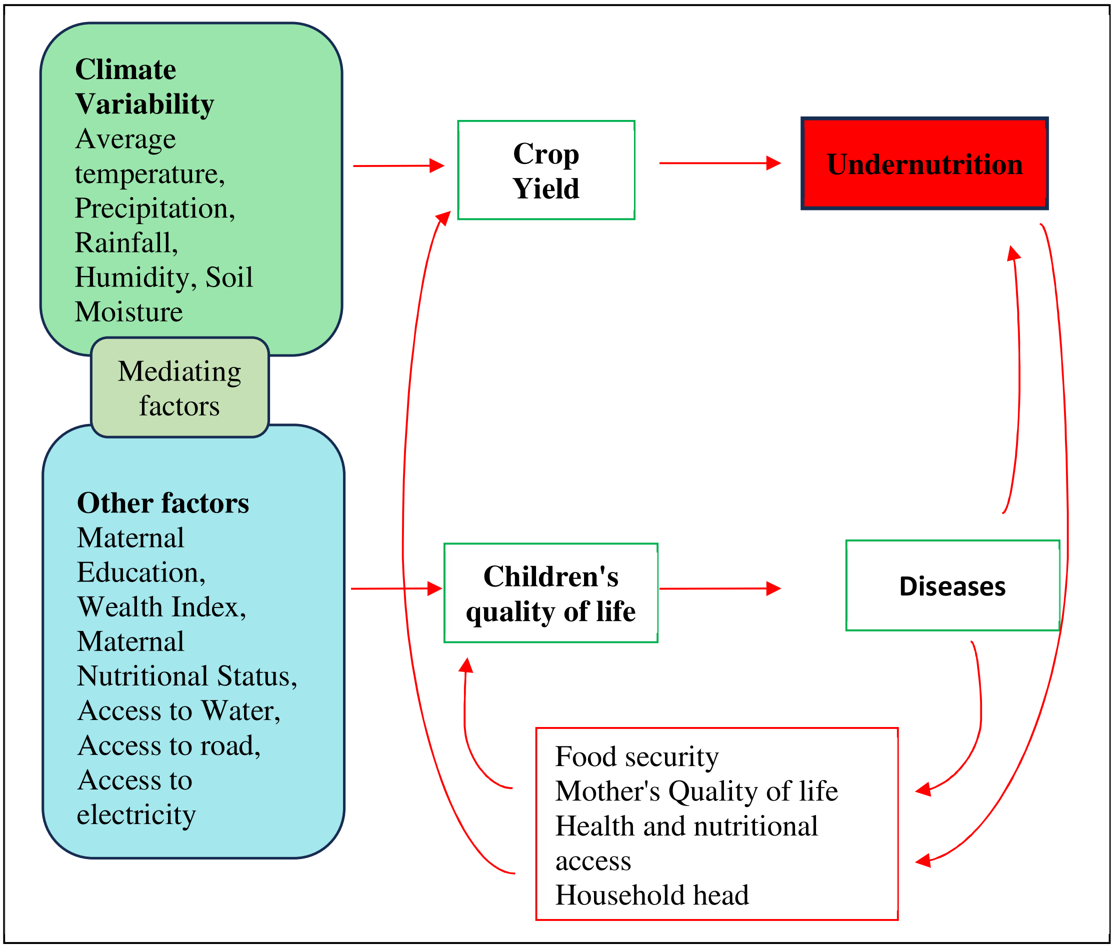

Fig. 4: Vicious pathways relating climatic factors to undernutrition. The factors connected to climate variables and their potential effects on crop yield and undernutrition.

suggests that climate factors, including household factors, are more closely associated with undernutrition (Tiwari et al. 2022, Thiede & Gray 2020, Tusting et al. 2020). This review, however, indicates that climate variability plays a similarly significant role in determining undernutrition in children.

The mechanisms linking malnutrition and climate variability are too complex for this study to fully explore. This review, however, identifies several significant mechanisms that may mediate this relationship, such as decreased crop yields and elevated incidence of other illnesses like malaria and diarrhea (Dimitrova 2020, Agostoni et al. 2023). These results highlight how crucial it is to use sustainable farming and healthcare practices as technological tools to counteract the detrimental effects of climate variability on children's nutrition. Gender was found to be an insignificant moderating factor in our studies. However, according to a study, boys are more susceptible than girls to the negative impacts of climate change on undernutrition (Lieber et al. 2022). Several factors that lessen the impact of climatic variability on undernourishment were also highlighted in this review. Among them, age is one of the most important; children are most vulnerable to changes in climate variables between the ages of 0 and 5 years. Nevertheless, this variable was not significant in the Mali study (Johnson & Brown 2014).

The majority of the study children analyzed in the papers that were reviewed were classified as vulnerable because of factors related to the climate, maternal education, children's nutritional status, and wealth status (Le & Nguyen 2022, Shively et al. 2022, Dimitrova & Bora 2020, Fenta et al. 2021, Khan et al. 2023). This may imply that undernutrition is never caused by temperature, precipitation, drought, or other weather-related factors alone but rather that undernutrition is triggered in children who are already at risk. The majority of research indicates that there is room to improve intervention programs' efficacy, especially their preventative components. This can entail fusing long-term preventative initiatives with short-term response interventions, focusing on various pathways that mitigate the effects of climate variability and attend to additional sources of vulnerability. Although there is general agreement that nutrition and climate variables are related, this relationship is often complex and indirect. Reduced food production is a result of higher temperatures and more frequent rainfall, which affects the amount and quality of nutrients ingested (Van et al. 2022, Haile et al. 2018).

This review primarily concentrated on malnutrition in low- and middle-income countries where a significant proportion of the populace relies on subsistence farming as a means of subsistence (Fantom & Serajuddin 2016). We did not mean to exclude the relatively small number of studies that looked at the relationship between undernutrition and climate variability in high-income countries, but that was one of the selection criteria. The results of this review may, therefore, not apply to children in more developed nations where subsistence farming is not as common. However, these studies are useful in emphasizing how common undernutrition is in LMICs during the high temperature, rainfall, and drought events that are studied, covering the full range of years from 1992 to 2019. As part of the Sustainable Development Goals (SDG) agenda, the global community has set a target of eliminating all forms of malnutrition worldwide by 2030. To this end, efforts are being made to develop measures, track progress, and put policies into place (Villanueva 2022). According to the WHO, these levels demand both immediate attention and the long-term development of preventative measures. The findings of our analysis imply that exposure to climate variables may be linked to an increased risk of undernutrition both during and for several years following climate events (United Nations 2022).

CONCLUSION

Without a doubt, determining the mechanisms by which undernutrition is impacted by climate change is a difficult task that needs to be tackled. Both the direct effects of crop yields on childhood undernutrition, particularly acute undernutrition and the influence of climate variability on crop yields have been extensively studied and recognized. There is a strong correlation between weather variables and childhood underweight and wasting, despite the limited evidence currently available. Nevertheless, a relatively small number of primary data-based studies examine the fraction of all undernourished children that can be linked to climate variability. Understanding the relationship, ideally at both the macro and micro levels, between crop yields, climate variability, and undernutrition in children is imperative. It is, therefore, important to methodically document these associations over the coming years, even "with associated uncertainties," as this could contribute to the creation of more accurate projections for the future.

According to IPCC and World Health Organization projections, undernutrition will account for the majority of morbidity and mortality caused by climate variables (WHO 2019, IPCC 2022). We provide a comprehensive literature review that connects child undernutrition and proxies for climate variability. We discovered that the nexus between climate variables and at least one undernutrition parameter in 19 out of 22 studies was found to be significant.

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