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Review article

Drought exposure as a risk factor for child undernutrition in low- and middle-income countries: A systematic review and assessment of empirical evidence

Kristine Belesova[a,*], Caroline Noel Agabiirwe[b], Margaret Zou[a], Revati Phalkey[b,c], Paul Wilkinson[a]

[a] Department of Public Health, Environments and Society, London School of Hygiene & Tropical Medicine, London, UK
[b] Division of Epidemiology and Public Health, School of Medicine, University of Nottingham, Nottingham, UK
[c] Institute of Public Health, University of Heidelberg, Im Neuenheimer Feld 324, Heidelberg 69120, Germany

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ABSTRACT

Background: Droughts affect around 52 million people globally each year, a figure that is likely to increase under climate change.

Objectives: To assess the strength of empirical evidence on drought exposure as a risk factor for undernutrition in children < 5 years of age in low- and middle-income countries (LMICs).

Methods: Systematic review of observational studies published between 1990 and 2018 in English and reporting undernutrition outcomes in children < 5 years of age in relation to droughts in LMICs. The search was performed in the Global Health, Medline, Embase, and Scopus databases. We assessed the strength of evidence following the Navigation Guide.

Results: 27 studies met our inclusion criteria. 12 reported prevalence estimates in drought-affected conditions without comparison to unaffected conditions. These showed high prevalence of chronic and mixed undernutrition and poor to critical levels of acute undernutrition. Only two studies were judged to have low risk of bias. Overall, the strength of evidence of drought as a risk factor was found to be *limited*, but the two studies with low risk of bias suggested positive associations of drought exposure with children being underweight and having anaemia.

Conclusion: Published evidence suggests high levels of all types of child undernutrition in drought-affected populations in low-income settings, but the extent to which these levels are attributable to drought has not been clearly quantified and may be context specific. This review offers suggestions for enhancing the quality of future studies to strengthen evidence on the potential magnitude, timing, and modifying factors of drought impacts.

1. Introduction

Of all the natural hazards of 20th century, droughts have produced the greatest adverse impact on human populations (Mishra and Singh, 2010). On average, 52 million people globally have been affected by drought each year over the period of 1990–2012 (Guha-Sapir et al., 2013). The 2016 El Niño threatened the food security of 60 million people across East and Southern Africa, Central America and the Pacific with USD 3.9 billion requested for response provision (World Food Programme, 2016; UN Office for the Coordination of Humanitarian Affairs, 2016). According to the Intergovernmental Panel on Climate Change (IPCC), the severity and frequency of droughts is likely to increase in the 21st century in West Africa and the Mediterranean (IPCC, 2012).

Through extreme weather events, such as droughts, and gradual changes in crop productivity, with subsequent changes in food availability, climate change is projected to increase the current global burden of child undernutrition (specifically, stunting) by 10.1 million additional stunted children by 2050 (Nelson et al., 2009). An even

Abbreviations: IPCC, Intergovernmental Panel on Climate Change; HAZ, height-for-age Z-score; HIV, Human Immunodeficiency Virus; LMICs, low- and middle-income countries; MUAC, middle-upper arm circumference; NCHS, National Centre for Health Statistics; NGO, non-governmental organisation; WAZ, weight-for-age Z-score; WHO, World Health Organization; WHZ, weight-for-height Z-score

* Corresponding author at: Department of Public Health, Environments, and Society, London School of Hygiene & Tropical Medicine, 15-17 Tavistock Place, London WC1H 9SH, UK.

E-mail addresses: Kristine.Belesova@lshtm.ac.uk (K. Belesova), Margaret.Zou@lshtm.ac.uk (M. Zou), Revati.Phalkey@nottingham.ac.uk (R. Phalkey), Paul.Wilkinson@lshtm.ac.uk (P. Wilkinson).

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further increase is projected through changes in incomes and affordability of food for the poorest 20% of the global population (Lloyd et al., 2018). Undernutrition in early life is a challenge for child survival as well as health and productivity of the survivors. It was estimated to be responsible for 45% of the 5.4 million deaths in children under five in 2017 (Lloyd et al., 2014). Adults, who were undernourished in childhood, have higher risk of chronic (Black et al., 2013) and infectious (Dercon and Porter, 2014) disease, compromised cognitive development (Ampaabeng and Tan, 2013), and lower economic productivity (Dewey and Begum, 2011). Furthermore, child undernutrition could point to the underlying vulnerabilities of population, such as a high prevalence of infectious diseases, poverty, poor infrastructure and limited market access, which channel drought impact on child nutritional status but also compromise wellbeing and quality of life in their own right. Therefore, it is particularly important to understand and address the impacts of drought on undernutrition specifically among children (conventionally below 5 years of age).

Although progress in decreasing the levels of global child undernutrition has been made since 1990, the rate of the progress has slowed (United Nations, 2015). Some argue, that progress may be reversed due to the effects of climate change and the increasing magnitude and frequency of extreme weather events such as droughts (Nelson et al., 2009; Lloyd et al., 2011; Nelson et al., 2010; Parry et al., 2009; Schmidhuber and Tubiello, 2007; Springmann et al., 2016).

The global policy agendas on climate change, health, and disaster risk reduction acknowledge the possible impact of climate change and weather-related disasters on undernutrition (Campbell et al., 2008; Corvalan et al., 2008; IPCC, 2014; United Nations Office for Disaster Risk Reduction, 2015). It is recognised that development of effective preventative approaches, such as undernutrition and drought early warning systems alongside other strategies for the reduction of the underlying vulnerability, are necessary (Centers for Disease Control and Prevention, 1991; Mude et al., 2009; Phalkey et al., 2015; Verdin et al., 2005). To enhance the effectiveness of preventative approaches, it is important to examine the evidence characterising the possible magnitude and time-course of drought impacts on each type of undernutrition (*e.g.*, acute, chronic, mixed, and micronutrient, see Table 1), as well as the effect of potential modifying influences, some of which could inform on the aspects of vulnerability that are adaptable for the reduction of future drought impacts.

Evidence relating to the effects of drought on undernutrition has not been reviewed in enough detail to address these questions, particularly with regards to one of the most vulnerable population groups – children in low-income settings. So far, two literature reviews have provided broad messages concerning the negative impact of drought on the nutrition of people of all ages, without differentiating effects by type of nutritional outcomes (Alpino et al., 2016; Stanke et al., 2013). The strength and quality of their synthesised evidence has not been systematically assessed. To inform the development of effective responses, it is essential to assess the robustness of the available evidence, identifying major methodological shortcomings for the improvement of future research.

Table 1
The examined undernutrition outcomes and their measures.

Undernutrition outcomes	Measure	Abbreviation
Acute undernutrition	Weight-for-height Z-scores	WHZ
	Middle-upper arm circumference	MUAC
	Global Acute Malnutrition	GAM
Chronic undernutrition	Height-for-age Z-scores	HAZ
Mixed undernutrition	Weight-for-Age Z-scores	WAZ
Micronutrient undernutrition	Vitamin (*e.g.*, A, B, C) and micro-mineral (*e.g.*, iron, iodine, zinc) deficiencies	–
Other	Length and height	–

In this paper, we review published (peer-reviewed) evidence on observational studies of undernutrition among children < 5 years of age in relation to droughts in low- and middle-income countries (LMICs). Our objective was to answer the question: "Is drought exposure a risk factor for undernutrition in children < 5 years of age in low- and middle-income countries?" We developed a "Participants", "Exposure", "Comparator", and "Outcomes" (PECOS) statement as follows:

- Participants: population of children < 5 years of age in LMICs
- Exposure: drought event(-s), as defined by the authors of the original studies
- Comparators: not essential, but where available, it was a comparable population unexposed to a drought or the same population at a time when it was not exposed to a drought
- Outcome: undernutrition outcomes (listed in Table 1)
- Study design: observational studies including measurement of nutritional outcomes.

We aimed to examine any evidence that relates to the magnitude and time-course of drought impacts as well as factors that may modify these effects. We assessed the strength of evidence on drought effects for each type of undernutrition (acute, chronic, mixed, and micronutrient), identifying methodological shortcomings, and providing recommendations for the improvement of the evidence base. Recently new approaches have been developed for systematic assessment of the quality and strength of observational evidence (Stewart and Schmid, 2015; Lynch et al., 2016; Rooney et al., 2014). This paper provides one of the few systematic reviews applying such assessment to the evidence of the health impacts of environmental factors and extreme events (Stewart and Schmid, 2015; Bonafede et al., 2016; Amegah et al., 2016).

2. Methods

2.1. Search methods

We searched the literature in Ovid Medline, Global Health, Embase, and Scopus, restricting our search to studies published in English with publication date from 1 January 1990 to 4 November 2018. In Embase and Medline, the search was limited to studies on humans (this filter was not available in other databases). We also screened reference lists of the two prior systematic reviews on the health impacts of drought (Alpino et al., 2016; Stanke et al., 2013). The search was initially run on 12 December 2013, and last updated on 4 November 2018. Trying to identify higher quality studies, we decided to exclude the grey literature due to large number of reports whose quality would have been difficult to assess.

The search strategy combined terms describing: drought exposure, possible undernutrition outcomes, and LMICs as defined by the World Bank classification (see Supplementary Table S1). The search strategy was constructed by KB, reviewed by PW and an expert in systematic review searches at the library of the London School of Hygiene and Tropical Medicine. We adapted the search strategy for each database by adding specific key words and synonyms identified in their thesauri and by adjusting the search syntax. Databases were searched by article abstracts, titles, key words, and headings (.mp).

2.2. Inclusion and exclusion criteria

Papers were included according to the following criteria: peer-reviewed full text reports of empirical observational studies, published since 1990 in English, which reported undernutrition outcomes such as acute, chronic, mixed (or the state of being underweight), and micronutrient undernutrition but also other relevant anthropometric measures (Table 1) among children < 5 years of age in relation to droughts (as defined by the authors of the original studies), in LMICs (as defined by the World Bank in April 2013) (see Supplementary Table S2). We included a broad range of observational study designs, with and without a control population, in order to assess the robustness and methodological aspects of the full range of the available peer-reviewed evidence. We excluded non-peer reviewed publications and papers not reporting on empirical observational studies (*e.g.*, commentaries, literature reviews), studies on non-human subjects, age groups other than children < 5 years, exposures other than drought events (*e.g.*, residence in arid and drought-prone areas), other health outcomes or measures of food security and intake, studies in high-income countries, published before 1990 or in languages other than English (see Supplementary Table S2).

2.3. *Study selection and data extraction*

Search results were combined and duplicates removed. Titles and abstracts were screened against the inclusion criteria (see Supplementary Table S2), leaving studies for which inclusion was uncertain from these records for the full text eligibility review. No exclusions were made based on the study quality to permit the assessment of any methodological shortcomings and the strength of evidence (Amegah et al., 2016). Table 2 indicates who of the authors performed study selection and data extraction. In selecting the studies, independent judgements of authors differed in 9% of the studies, and were resolved through discussion, and when necessary, consulting third reviewer (3% of studies).

Data from the included papers was extracted into a pre-defined data extraction sheet with the following variables: country and location of the study, study aim, design, type of data used (primary or secondary), source of secondary data, sample size, sampling strategy, year(-s) of the drought, year(-s) of data collection, age of study subjects, outcome measures, outcome results, results on possible effect modification, drought description, drought exposure measures, authors' provided definition of drought, study context (setting and population), concurrent events, any interventions (existing or implemented in response to the drought).

2.4. *Assessment of evidence*

To assess the strength of evidence provided by reviewed articles, we followed the Navigation Guide framework (Woodruff and Sutton, 2014; Johnson et al., 2014). The Navigation Guide provides guidelines on the assessment of the quality and strength of evidence and systematic synthesis of research in environmental health, including separate guidelines specifically for observational human studies (Lynch et al., 2016; Woodruff and Sutton, 2014; Johnson et al., 2014). The three stages of the assessment are: assessment of the risk of bias in individual studies, assessment of the quality of evidence and assessment of the strength of evidence across studies for each outcome type (Woodruff and Sutton, 2014; Johnson et al., 2014; Lam et al., 2014). At each stage the assessment was performed by two authors independently, resolving any disagreement through discussion, and, if necessary, by consulting a third reviewer (Table 2).

2.4.1. *Assessment of the risk of bias in individual studies*

We assessed each study against 10 domains of the risk of bias as *low risk*, *probably low risk*, *probably high risk*, *high risk*, *not applicable*, or *unclear* using an adaptation of the methods described by Johnson et al. (2014, 2016) (see Supplementary note 1). To the nine original domains of assessment of Johnson et al. we added an additional domain of assessment of migration or survival bias for studies undertaken in circumstances when substantial movements of people or increased mortality might have occurred prior to data collection (Johnson et al., 2014; Johnson et al., 2016); there were appreciable movements of people in some of the reviewed studies with the potential to introduce such bias (Gari et al., 2017). These aspects are not covered by the original assessment domains of the Navigation Guide when it is applied to a wider range of observational study designs, particularly single or repeated cross-sectional studies. We adapted Johnson and colleagues' instructions (Johnson et al., 2014; Johnson et al., 2016) for the assessments of drought exposure and undernutrition outcomes; we assessed as *probably low* (as opposed to *low*) the risk of bias from the involvement of governmental agencies and non-governmental organisations (NGOs). For the domain of recruitment assessment we also took into consideration the consistency of sampling methods across subjects with different drought exposure levels. As per Navigation Guide method, a study was considered to have *low* or *probably low* risk of bias, if the risk of bias was judged as *low* or *probably low* across all domains of assessment.

2.4.2. *Assessment of the quality of evidence across studies*

We assessed the quality of evidence across studies for each type of undernutrition (*e.g.*, acute, chronic, mixed, micronutrient undernutrition) separately. Following the approach of the Navigation Guide, we rated the evidence as *high*, *moderate*, or *low*, initially assigning the rating as *moderate*, and then considering adjustments based on the following factors: risk of bias across studies, indirectness of evidence, imprecision, publication bias, size of the effect (since with a larger magnitude of the effect confounding alone is less likely to explain the association), dose response pattern, and whether confounding could minimise the effect. The risk of bias across studies was based on the outcome of our assessment of the risk of bias in individual studies, explained in the previous section. To judge the risk of bias across studies, we considered the contribution of each study with a general focus on high-quality studies, as per the Navigation Guide (which recommends against integration based on any quantitative scoring methods) (Johnson et al., 2014; Johnson et al., 2016). The assessment was performed as per Johnson and colleagues' instructions (Johnson et al., 2014; Johnson et al., 2016).

2.4.3. *Assessment of the strength of evidence across studies*

We also rated the strength of the body of evidence by type of undernutrition, based on: quality of the body of evidence (*i.e.*, rating from the previous stage of assessment), direction of effect (*i.e.*, plausible consistency across studies on whether drought exposure suggests increased or decreased levels of undernutrition), confidence in the effect (likelihood of a new study changing our conclusion), any other

Table 2
Authors responsible for the study selection, data extraction, and the assessment of evidence.

	Results of the initial search (12 December 2013) and the first update (19 August 2016)	Results of the last update (4 November 2018)
Eligibility assessment	KB and RP, in cases of disagreement consulting PW	KB and MZ, in cases of disagreement consulting PW
Data extraction	KB, verified against the full text papers by CA	MZ, verified against the full text papers by CA
Assessment of the risk of bias in individual studies	KB and CA, in cases of disagreement consulting PW	CA and MZ, in cases of disagreement consulting KB
Assessment of the quality and strength of evidence across studies	KB and PW	KB and PW

attributes that may affect certainty, as explained by Johnson and colleagues (Johnson et al., 2014; Johnson et al., 2016). No modification was made to the approach of the assessment of the strength of evidence (Woodruff and Sutton, 2014; Johnson et al., 2014; Lam et al., 2014).

2.5. Synthesis of results

Quantitative synthesis in a form of meta-analysis or a forest plot was not appropriate due to the diverse range of study designs and other methodological and contextual heterogeneity. Therefore, study findings, which included diverse measures of drought effect on child undernutrition outcomes (Table 1), are synthesised narratively. We performed narrative synthesis in two stages: (1) preliminary synthesis using grouping (by outcome type, study design, risk of bias) and tabulation techniques, (2) exploration of relationships within and between studies to characterise the extent of drought impact on each type of child undernutrition (acute, chronic, mixed, micronutrient) and effect of factors may modify these impacts (Popay et al., 2006). To synthesise evidence on effects of potentially modifying factors, between study comparisons were only feasible and performed in relation to the presence of relevant interventions in a subset of studies that explicitly reported either their presence or absence. Due to sporadic reporting of drought severity and presence of other contextual factors, between study comparisons were not feasible in relation to the other factors, hence, only within study comparisons were performed for the synthesis of evidence on their modifying effects.

3. Results

3.1. Study selection

A flowchart of study selection is presented in Fig. 1. Our search identified 7137 unique records. On the basis of screening titles and abstracts of these records against the inclusion criteria, we excluded 7033 records, leaving 103 records for full text review. Following the full text versions of the 103 papers against the inclusion criteria, we excluded 77 papers: 23 for not examining the impacts of drought, 21 for not reporting undernutrition outcomes, 20 for not being peer-reviewed articles on empirical studies, 11 for not reporting on children < 5 years of age, one for being an earlier (repeated) published version of an already included study, and one for not reporting undernutrition outcomes measured in the conditions with and without drought exposure separately (see Supplementary Table S1). One additional study was identified from a lateral search of reference lists of the prior reviews (Alpino et al., 2016; Stanke et al., 2013). 27 articles were included in the review.

3.2. Study context

The included studies covered 20 different countries. Twenty-three were single country studies, with a majority in Eastern Africa (nine studies) and India (six studies) but also in Mali, Haiti (Centers for Disease Control and Prevention, 1991), Afghanistan (Assefa et al., 2001), North Korea, Indonesia, Senegal, Pakistan, and Lesotho. Four were multi-country studies covering Eastern and/or Southern Africa. Seventeen studies examined rural populations, one an urban population, and five both rural and urban populations. Others did not specify.

Eight studies were conducted in cases where high undernutrition impact was already suspected. Authors described the situation as famine, based on official information or anecdotal evidence of high levels of undernutrition, starvation deaths, or increased mortality.

Contextual factors were not described by all articles but, when mentioned, emphasized the vulnerability of the study settings: the worst affected areas, drought-prone areas, high prevalence of Human Immunodeficiency Virus (HIV), peak malaria time, poorest areas of the country, other agriculturally damaging disasters such as floods, wildfires, and hailstorms happening concurrently or shortly preceding the drought, economic decline or volatile commodity prices, government

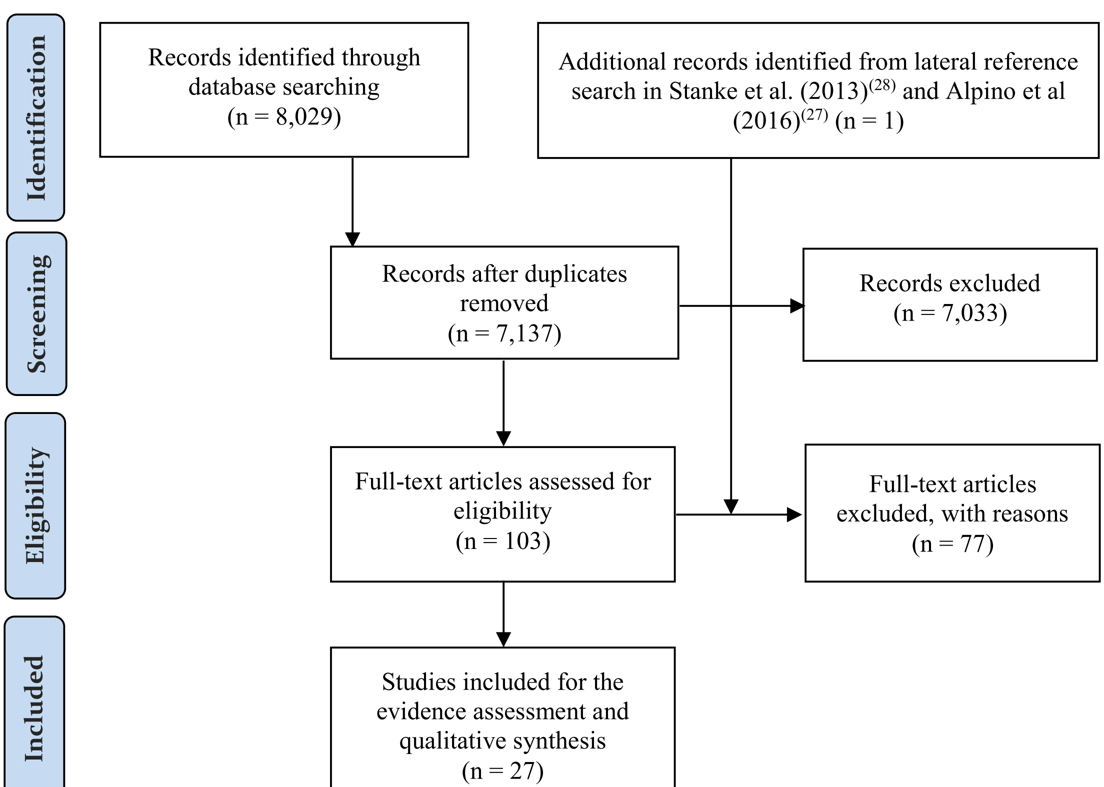


Fig. 1. Flow chart of the study selection process and the number of records considered at each stage.

Table 3
The reviewed study characteristics and key results.

Source	Location, drought year	Event characteristics	Context	Data collection period	Sample size	Age, months	Study design	Outcome measures	Key results
Ahsan et al., 2017	Pakistan, four villages in Tharparkar district, 2011–2014	Third consecutive drought year	Rural, poor drought response	2014	304	6–59	Cross-sectional. No control	WAZ, WHZ, HAZ	-Stunting 38.5%, wasting 19.1%, underweight 33.2% (Z-score < -2 SD)
Arlappa et al., 2011	India: Karnataka, Andhra Pradesh, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, 2003	Most severely drought affected states	Rural, recurrent droughts, high vitamin A def. baseline levels	2003	3657	12–59	Cross-sectional. With control	VAD (Bitot's spots)	-Higher prevalence of Vitamin A Deficiency (VAD) in drought affected areas (1.8%) than in unaffected areas (0.9%), OR 2.0, 95% CI 1.6, 2.7.
Assefa et al., 2001	Kohistan district, Faryab province, Afghanistan, 1998–2001	Third consecutive drought year, loss of productive capacity, assets, livelihoods	Civil war, displacement, remote location, poor health care services	2001	708	6–59	Cross-sectional. No control	WHZ, HAZ	-Under 5 mortality rate (U5MR) 5.9 (95% CI 2.0, 8.8) per 10,000 per day -Prevalence of stunting 63.7% (95% CI 58.6, 68.8%) with 34.6% severe stunting (95% CI 29.5, 39.7%) -Prevalence of wasting 7% (95% CI 5.9, 9.0%) with 1.1% (95% CI 0.2, 1.5%) severe wasting
Bauer and Mburu, 2017	Kenya, Marsabit district (Central, Maikona, Loiyangalani, Laisamis eco-regions), 2009–2013	Drought exposure determined from NDVI Z-scores relatively to the period average NDVI values	Rural, arid/semi-arid area, prone to droughts and hunger, pastoralist population, high levels of child undernutrition	2009–2013	3302	12–60	Longitudinal	MUAC Z-score	-Significant, negative effect of drought on MUAC: 1 SD decrease in the NDVI z-score associated with 12–16% increase in the average probability of undernutrition
Block et al., 2004	Rural Java, Indonesia, 1997–1998	Severe drought linked to El Niño, low rainfall and harvest, food shortages, inflation	Economic crisis, inflation, political instability, wildfires, rural	1995–2005	107,753	0–36 and 0–59	Longitudinal	WAZ, blood Hb levels	-No effect on being underweight, adjusted for age & cohort effects -Increased prevalence of anaemia (from 52% to 68% or blood haemoglobin (Hb) levels 10.36 *vs* 11.0 g/dl)
Carnell and Guyon, 1990	Timbuktu region, Mali, 1983–1985	Drought across Sahel, reached famine in Mali, migration to urban areas	Rural, 30% nomads, rural-urban migration	1985	1798	0–59	Cross-sectional. No control	WHZ	-Prevalence of wasting 28%, severe wasting 0.5% -Prevalence of wasting was significantly higher in children 12–23 months of age (44% under -2SD and 12% under -3SD of the NCHS median) -Annual Crude mortality rate (CMR) of 39 per 1000 people -Annual U5MR of 76 per 1000 children < 5 years
CDC, 1991	Nord-Ouest, Nord, Nord-Est, Artibonite, Haiti, Centre, 1990	Severe drought, low food supply, famine, most affected areas	Not described	1990	967	3–59.9	Cross-sectional. No control	HAZ, WAZ, WHZ	-Prevalence of undernutrition: 40.6% chronic, 4.2% acute, 34% mixed
Chotard et al., 2010	Eritrea, Ethiopia, Kenya, Sudan, Somalia, Uganda, 2000–2006	Drought determined from records in nutrition surveys	Low rainfall areas, migrant, pastoralist, agriculturalist, mixed groups	2000–2006	897 (sub-) national nutrition surveys	0–59.9	Cross-sectional. Repeated in multiple sites, time points	WHZ or GAM	-Drought years associated with higher prevalence of wasting, *e.g.*, 5% increase in the drought year 2000 ($p < 0.001$)
De Waal et al., 2006	Ethiopia (national), 2002/3	A widespread drought during the main growing season affected 13.2 million people, relief requested	Drought prone, famine & urban, political inefficiency, environmental degradation, volatile prices	2004	4816 households, no. of children not reported	1–59 (HAZ) 0–59 (deaths)	Cross-sectional. No control	HAZ, mortality	-Prevalence of stunting 57% -Higher prevalence of stunting in drought-affected areas than unaffected areas (numerical results not reported) -Mortality rates of 94 and 134 per 1000 live births among infants and

(*continued on next page*)

Table 3 (*continued*)

Source	Location, drought year	Event characteristics	Context	Data collection period	Sample size	Age, months	Study design	Outcome measures	Key results
									children respectively. Higher in drought-affected areas (than unaffected areas): infants 109 (86), children 1–4 years 55 (39), < 5 years 158 (121) per 1000 life births. Adjusted drought effect not significant ($p = 0.8$)
Gari et al., 2017	Ethiopia, Adami Tullu district, 2015–2016	Severe drought triggered by El Nino	Rural area prone to droughts and food shortage, rain-fed subsistence agriculture and cattle rearing, high levels of malaria	2014, 2015	2984 (2014), 3128 (2015)	6–59	Cross-sectional. Repeated at multiple time points. A longitudinal component.[a]	WAZ, WHZ, HAZ, anaemia	-From 2014 to 2015, an increase in the prevalence of stunting and anaemia from 44.8% to 50.7% ($p < 0.001$), 28.2% to 36.8% ($p < 0.001$); a decrease in the prevalence of wasting and underweight from 7.3% to 4.1% ($p < 0.001$) and from 18.5% to 15.4% ($p < 0.001$) -Incidence rate of anaemia between 2014 and 2015: 30 (95% CI 28, 32) and 28 (95% CI 25, 31) cases per 100 child–years of observation in a dynamic and closed cohort, respectively
Gitau et al., 2005	Maternal & child clinic in Lusaka, Zambia, 2001–2002	Regional drought, doubled the price of maize	Urban, in clinic, middle class, half of the mothers HIV+	2001–2003	429 0–1.5 months; 354 0–4 months	0–4	Longitudinal	Length and weight	-Lower length Z-scores of infants exposed to drought-related maize price increase when measured at the age of 6 and 16 months, and those exposed *in utero* -No significant decline in weight Z-scores with price increase
Katona-Apte and Mokdad, 1998	Kangwon, South: Hwanghae, Pyongan, Hamgyong, N. Korea, 1997	Historically one of the worst droughts, agricultural loss, food shortages despite aid	Tidal wave, hailstorm, flood, subsidy & ration system	1997	2275	0–59	Cross-sectional. No control	WHZ, HAZ	-Proportions of wasted (and severely wasted) children by age groups < 6 months, 6 months–2 years, 2–5 years were: 16.7% (2.1%), 27.8% (5.8%), 14.8% (1.4%), stunted respectively: 0% (0%), 29.2% (10.9%), 38.6% (18.9%)
Kumar and Bhawani, 2005	Baran district in Rajasthan, India, 1998–2002	5th drought year, loss of livestock & crops, migration, starvation deaths, economic loss	Rural, backward, semi-arid region; high malaria impact	2002 and 6 months later	$n1 = 3206$, $n2 = 1775$	0–59	Cross-sectional. Repeated in multiple time points	WAZ, WHZ	-After the drought but prior to the interventions, prevalence of underweight children was 63.4% (28.3% severe), wasting 27.3% (4.7% severe) -After the drought and after the interventions prevalence of underweight children was 59.6% (26.1% severe)
Kumar et al., 2016	India (national), 2002–2004	Drought defined as a decrease in rainfall (Jun–Sep) below 75% of the long-term average at the district level	Rural, mostly rain-fed agriculture	2002–2004	149,386	0–59	Cross-sectional. Repeated in multiple sites and time points	WAZ, anaemia	-Drought in the year of birth and year before birth was significantly associated with WAZ ($p < 0.001$), with being severely underweight ($p < 0.05$) and somewhat with being moderately underweight ($p < 0.05$ and $p < 0.10$) -Drought in early life estimated to

(*continued on next page*)

Table 3 (*continued*)

Source	Location, drought year	Event characteristics	Context	Data collection period	Sample size	Age, months	Study design	Outcome measures	Key results
									increase mean probability of being underweight by 2% -Drought in the year before birth (but not in the year of birth) was strongly associated with anaemia (Hb < 11 g/dl) -Drought in the year of birth was significantly associated with infant mortality (rate ratio of 3.49, SD 1.44)
Lazzaroni and Wagner, 2016	Senegal: Diourbel, Thies Fatick, Kaolack, Kolda, Louga, Kedougou, Tambacounda 2009 & 2011	Household self-reported drought exposure	Macro-economic shocks (food price increase), national health programme response, subsistence agriculture, rural	2009, 2011	1694 (2009) 2116 (2011)	12–60	Cross-sectional. Repeated in multiple time points and sites	WAZ	-24.5% of pooled variation in WAZ explained by drought exposure, suggesting a substantial negative association
Lindtjørn, 1990	Arero and Borana provinces, Ethiopia, 1984–1986	Severe drought and famine, 10% of the study population moved to relief shelters during the drought	Civil war, seminomadic pastoralists, sampled from food distribution sites	1985, 1986	14,173 in 1985; 5334 in 1986	12–59	Longitudinal[b]	Mortality, WHZ	-Mortality risk ratio peak drought *vs* post-drought: 2.26 (95% CI 1.89, 2.70); higher risk in famine relief shelters ($p < 0.01$) -Prevalence of wasting during drought (*vs* no drought): Arero pastoralists 4.1% (3.3%), shelter populations 13.7% (5.7%), agropastoralists 3.7% (5.3%), Borana pastoralists 13.0% (3.1%), shelter populations 20.4%
Mahapatra et al., 2000	Kalahandi district, Orissa, India, 1996–1997	Not described	Rural, backward, mostly landless agricultural labourers	1996–1997	751	0–59	Cross-sectional. No control	WAZ, WHZ, HAZ, micronutrient def. (clin. sign)	-Prevalence of underweight children 57.1% (21.2% severe), wasting 27.9% (6.7% severe), stunting 41.8% (17.4% severe), marasmus 0.7%, clinical signs of protein-energy undernutrition 4.5% (among 1–5 years olds), clinical signs of vit. B deficiency 5.8%, vit. A deficiency (Bitot's spots) 1.3% (among 2–5 years olds), kwashiorkor absent
Mason et al., 2005	Lesotho, Zambia, Mozambique, Swaziland, Malawi Zimbabwe, 2001/2	Severe food crisis, mild drought, increased food prices, famine deaths	HIV, poverty, market failure, recession, conflict, political disorder, flooding in Malawi	1992–2002	Multiple surveys, number not specified	6–59 and 6–36	Cross-sectional. Repeated in multiple sites and time points	WAZ	-Prevalence of underweight children increased from 2001 (drought year) onwards, as compared to the preceding years, in all countries except Lesotho; highest increases: 5 to 20% in Maputo (Mozambique, 1997–2002), 17 to 32% in Copperbelt (Zambia, 1999–2001/2), 11 to 26% in Midlands (Zimbabwe, 1999–2002)
Mason et al., 2010a	Ethiopia, Kenya, Uganda, Lesotho, Malawi, Mozambique, Swaziland, Zimbabwe, Zambia, 2001–03	Drought defined based on food security & production data reported by FAO	Long-term trends of improving situation in undernutrition	1992–2006	45 national nutrition surveys	6–59	Cross-sectional. Repeated in multiple sites and time points	WAZ	-Prevalence of underweight children higher in drought *vs* non-drought years: 24.7% *vs* 21.3%; $p < 0.05$ in Southern African countries, and 28.0% *vs* 20.4% in the Horn countries -Food price weakly associated with

(*continued on next page*)

Table 3 (*continued*)

Source	Location, drought year	Event characteristics	Context	Data collection period	Sample size	Age, months	Study design	Outcome measures	Key results
									children being subsequent underweight -Drought had greater impacts in the Horn countries
Mason et al., 2010b	Ethiopia, Kenya, Somalia, Sudan, Uganda, various over 2000–2006	Drought defined based on FAO food security & production reports	Rural	2000–2006	897 (sub-) national nutrition surveys	0–59	Cross-sectional. Repeated in multiple sites and time points	GAM	-Droughts correspond with spikes in Global Acute Malnutrition (GAM) and U5MR in all areas of study
McDonald et al., 1994	Embu District of Eastern Province, Kenya, 1984	Severe drought, insufficient rains, crop failure, food shortage despite food aid	Small landholder agriculturalists producing both subsistence and market crops	1984	110	18–30	Longitudinal	Weight, WAZ	-Despite drought, body weight and WAZ increased smoothly for toddlers before, during, and after the drought with mean weight 9.5 kg (SD 1.2 kg), 10.2 kg (SD 1.2 kg), 10.8 kg (SD 1.2 kg) respectively and WAZ of −1.65 (SD 0.9), −1.58 (SD 0.9), −1.56 (SD 0.9) -No decline in toddler's growth-related weight gain
Moloney et al., 2011	Southern Somalia, 2011	Crop failure, food insecurity, livestock mortality, increased cereal prices, widespread undernutrition	Not described	2011	Not given	6–59	Cross-sectional. No control	GAM	-Prevalence of GAM was > 20% in all 15 livelihood zones -In 11 of the 15 zones, GAM exceeded the famine threshold of 30% (range: 39–55%) -In 4 zones CMR exceeded the famine threshold of 2 deaths/10,000 population per day (range: 2.2–6.1) -U5MR ranged from 4.1 to 20.3 deaths/10,000/day
Mude et al., 2009	Marsabit, Samburu, Turkana, Baringo districts, Kenya, 2000	Drought defined by failure of rains and low forage availability	Arid districts, various communities	2000–2005	3038: on average 50 monthly community aggregates	6–59	Repeated over time	MUAC (/age)	-Drastic decrease in MUAC levels during the drought in 2000, leading to famine conditions (20% or more of children with Z-scores < −2). Trends in rainfall and forage availability rates correlated with the increase
Renzaho, 2006a	Quthing, Mafeteng, and Mohale's Hoek districts, Lesotho, 2002–2003	Dry cropping season hampered sowing, low harvest, food insecurity, severe water shortages	Adult HIV/AIDS prevalence 13–34%	2005	738	6–59	Cross-sectional. No control	WAZ, WHZ, HAZ	-Prevalence of underweight children, stunting, and wasting was 15.6 (95% CI 8.8, 22.3)%, 33.7 (95% CI 25.7, 41.7)% and 10.9 (95% CI 6.5, 15.3)% among girls and 22.9 (95% CI: 15.1, 30.7)%, 38.5 (95% CI: 29.6, 47.4)% and 13.1 (95% CI 7.4, 18.8)% among boys, respectively -CMR was 0.8/10,000/day and U5MR was 3.2/10,000/day
Renzaho, 2006b	Tete province, Mozambique, 2002–2003	Drought due to insufficient rain, loss of productivity, food shortages, food insecurity	Food insecurity after several years of flooding, droughts, high levels of HIV	2004	874	6–59	Cross-sectional. No control	WAZ, HAZ, WHZ	-Prevalence of wasting was 8.0 (95% CI 6.2, 9.8)%, underweight children 26.9 (95% CI 24.0, 29.9)%, and stunting 37.0 (95% CI 33.8, 40.2)% -CMR 1.23 (95% CI 0.71, 1.35), U5MR 1.03 (95% CI 0.71, 1.35)/ 10,000/day
Singh et al., 2006	Jodhpur district, Rajasthan, India, 2003	Not described		2003	914	0–59	Cross-sectional. No control		-Prevalence of: wasting 39%, stunting 26%, vitamin deficiencies:

(*continued on next page*)

Table 3 (*continued*)

Source	Location, drought year	Event characteristics	Context	Data collection period	Sample size	Age, months	Study design	Outcome measures	Key results
			Rural, desert drought prone area, weak economy, low coping capacity					WAZ, HAZ, vit. A, B, C def., anaemia marasmus	A 0.7%, B 3%, C 0.1%, protein-energy undernutrition 44.4%, deficient calorie intake 76%, deficient protein intake 54%, prevalence of anaemia 30.5%
Venkaiah et al., 2015	India: Chhattisgarh, Karnataka, Andhra and Madhya Pradesh, Rajasthan, Tamil Nadu, Maharashtra, Gujarat, Orissa, 2002–03	Drought defined as Jun-Sep rainfall < 75% of long-term average in each state	Prone to recurrent droughts	2003	6037	Pre-school	Cross-sectional. No control	WAZ, WHZ, HAZ	-Across the states, prevalence of severe stunting ranged from 10.7 to 48.1%, severe wasting 0.9–7.4%, and underweight children 8.4–35.8%

Abbreviations: AIDS, Acute Immunodeficiency Virus; CI, confidence interval; CMR, crude mortality rate; FAO, Food and Agriculture Organization; HIV, Human Immunodeficiency Virus; HAZ, height-for-age Z-score; GAM, global acute undernutrition; MUAC, middle-upper arm circumference; NCHS, National Centre for Health Statistics; VAD, vitamin A deficiency; UM5R, under 5 mortality rate; WAZ, weight-for-age Z-score; WHZ, weight-for-height Z-score.

[a] The longitudinal component in Gari et al. (2017) study examined anaemia (as the only outcome) in two cohorts (a closed and a dynamic cohort) of non-anaemic children selected from their baseline survey of 2014.

[b] The study design in Lindtjørn (1990) was a prospective cohort with monthly repeated measurements of children's weight and height, results were presented as the prevalence of wasting at two points in time: during and after the examined drought event.

instability, war or armed conflict, and high baseline levels of the examined negative undernutrition outcomes. Only one study was conducted in a historical grain surplus production area.

Supplementary Table S3 lists studies corresponding to each of the contextual characteristics mentioned in this section.

3.3. Study characteristics

The characteristics of the included studies are available in Table 3. All were observational studies that examined drought impact on undernutrition outcomes of children < 5 years of age in LMICs. The studies were published in English in peer-reviewed journals from 1990 to 2018 but conducted on data collected from 1984 to 2015, with the majority from 1990 to 2005. Study sample sizes ranged from 224 (McDonald et al., 1994) to 149,386 (Kumar et al., 2016).

Twenty studies focused on a single specific drought event and five on multiple events. Only two articles provided a definition of drought. Most authors provided a descriptive reference to drought as an extreme event linked to low rainfall, low crop production and/or food insecurity, and a combination of the two, or as manifested by high staple crop prices. Hence, drought exposure in most papers was implied as a presence of an (undefined) drought event or expressed by such measures as rainfall, level of crop production, food security or food price index.

In terms of the outcome measures, eighteen studies examined measures of acute undernutrition, eleven of chronic undernutrition, fifteen of mixed undernutrition (also referred to as the state of being underweight), and six studies of micronutrient (vitamins A, B, C and iron) deficiencies. One study also examined infant length and height as anthropometric measures related to child nutritional status. Most outcome data was collected in the first year of drought. In five studies outcome data was collected in the second year, one in the third year, one in the fifth year of the drought, and in two studies one and two years after the drought. Nineteen studies were based on primary data. Ten studies were based on secondary data, which were derived from a prior cohort study, from programme monitoring and evaluation, and from other surveys (Demographic and Health Surveys, Multiple Indicator Cluster Surveys, other government and NGO, and international organisation surveys).

Study objectives, designs, and contexts varied (Tables 3 and 4). Depending on the design, studies had different potential to provide strong evidence of drought as a risk factor for child undernutrition (Table 4). Longitudinal, controlled or repeated (in conditions of different drought exposure levels) cross-sectional studies were generally viewed as providing stronger evidence (Table 4). Of all the reviewed studies there were six rapid emergency assessments and four assessments of interventions addressing drought impacts.

Supplementary Table S4 lists studies corresponding to the characteristics discussed in this section.

3.4. Assessment of the risk of bias in individual studies

The results of assessment in individual studies are summarised in Table 5 and synthesised across studies by type of undernutrition in Fig. 2. Assessment summaries for each study are available in Supplementary Tables S6 to S32.

We identified the lack of blinding, confounding, migration or survival, and outcome assessment as the most common sources of the risk of bias. None of the studies reported any attempt of blinding. Drought events received media coverage (Carnell and Guyon, 1990; Kumar and Bhawani, 2005; Ahsan et al., 2017) and government announcements (Block et al., 2004; De Waal et al., 2006; Mason et al., 2005; Renzaho, 2006a; Venkaiah et al., 2015), thus, potentially raising awareness among the personnel performing outcome measurements about drought exposure status of the study subjects. Therefore, all studies (100%) were judged to have *probably high* risk of observer bias. Assessment of confounding was relevant only to the studies examining drought exposure–outcome associations and had a comparator, *i.e.*, studies with longitudinal design and cross-sectional studies that were repeated over time or had a control site (see Table 4), 14 of the 27 studies. Of these, twelve (86%) were judged to have *high* or *probably high* risk of bias, as they did not control for some of the key confounders (*e.g.*, concurrent events posing risk to nutrition) or any confounders at all. Some studies were conducted in localised areas, after prolonged exposure to the droughts with likely outmigration and mortality of the most vulnerable prior to data collection. Fifteen studies of all 27 (56%) were judged to have *high* or *probably high* risk of migration or survival bias, as they did not account for the possible effects of these processes.

Nine (33%) studies were judged to have a *probably high* risk of bias in the outcome assessment, as they may have underestimated undernutrition prevalence as a result of either using the National Centre for Health Statistics (NCHS) child growth reference, which (as opposed to the standards based on the World Health Organization (WHO) Multicentre Growth Reference Study) does not represent ideal child growth (de Onis and Yip, 1996; de Onis et al., 2006), or by defining micronutrient deficiency based upon their clinical signs (as opposed to blood sample analysis) (Wyss, 2004; WHO, 1998).

Additionally, exposure assessment and assessment of incomplete outcome data were frequently hampered by the limited information reported in the articles, making it difficult to assess the risk of bias in their exposure assessment. Six (22%) of the studies did not provide data on the drought exposure of their study populations or even a reference to a source providing such data. Further, seven (26%) studies were judged to have *high* or *probably high* risk of bias in exposure assessment due to potentially biased measures or the lack of drought exposure ascertainment for their study area (*e.g.*, only claiming drought exposure at the country level), which is important because droughts are often patchy phenomena and may not affect large territories uniformly. Eleven studies (41%) did not provide sufficient information to enable the assessment of incomplete outcome data.

Across all assessment criteria, only two studies by Kumar et al. and Lazzaroni & Wagner (7%) were judged to have *low* or *probably low* risk of bias by all criteria (except blinding) (Kumar et al., 2016; Lazzaroni and Wagner, 2016). Three studies (11%) did not report sufficient detail to assess their risk of bias by some of the criteria but were judged to have *low* or *probably low* risk of bias by all criteria (except blinding) where sufficient information was reported. The remaining 22 (81%) studies were judged to have *high* or *probably high* risk of bias by more than one of the assessment criteria.

3.5. Quality of evidence across studies

A summary of the assessment of the overall quality of evidence on drought exposure as a risk factor for undernutrition in children < 5 years of age in low- and middle-income countries by type of undernutrition is presented in Table 6. We downgraded the rating of the overall quality of evidence for acute and chronic undernutrition by the criteria of publication bias and the risk of bias across studies. We also downgraded the rating for chronic undernutrition by the criterion of indirectness to reflect absence of studies on its association with drought exposure (all studies, except one, reported only uncontrolled prevalence estimates). We upgraded the quality of evidence for acute undernutrition, due to the high magnitude of the possible effect (over two-times increase in the prevalence under drought exposure). The resulting overall quality of evidence rating was *low* for acute and chronic undernutrition and *moderate* for mixed and micronutrient undernutrition.

3.6. Strength of evidence across studies

A summary of the assessment of the strength of evidence is also presented in Table 6. We made the following considerations for the strength of evidence. Quality of the body of evidence (as concluded above): *low* for acute and chronic undernutrition, *moderate* for mixed and micronutrient undernutrition. Direction of effect estimate: largely increasing for each type of undernutrition. Confidence in effect estimates: effect estimates were uncertain and often uncontrolled; new studies might show different estimates. Other compelling attributes of the data that may influence certainty: drought event characteristics, contextual factors, population vulnerability, and drought response may make the interpretation less certain and less clear. We concluded that there was limited evidence for (or against) drought exposure as a risk factor for each type of undernutrition among children < 5 years of age in LMICs.

3.7. Synthesis of findings on drought effect on child nutritional status

Key findings of each study are reported alongside study characteristics in Table 3.

3.7.1. Acute undernutrition

Acute undernutrition is sensitive to recent decreases in a person's weight, often related to a sudden decrease in food intake or an illness, both of which can be related to drought exposure. It was the most frequently examined type of undernutrition (18 studies). Six studies had designs that permitted examining its *association* with drought exposure or comparing acute undernutrition levels in conditions with and without drought exposure. Of these, five studies, undertaken in the Horn of Africa (Chotard et al., 2010; Mason et al., 2012), Ethiopia (Lindtjørn, 1990), and Kenya (Mude et al., 2009; Bauer and Mburu, 2017), suggested increases in acute undernutrition levels with drought exposure, which ranged from the minimum of 0.8 percentage point increase among pastoralists of Arero province of Ethiopia (Lindtjørn, 1990) to 25 percentage point increase in Kenya (Mude et al., 2009). By contrast, the sixth study reported a 3.2 percentage point decrease in the prevalence of acute undernutrition in a drought year as compared to a year without drought ($p < 0.001$) in the Tullu district of Ethiopia (Gari et al., 2017). In this setting communities were receiving food aid and benefited from increased efforts in screening and treating undernourished children (Gari et al., 2017). Poor reporting of contextual factors and drought intensity as well as differences in the study design did not permit further interpretation of factors that might have contributed to heterogeneity in the level of increase in acute undernutrition across studies. All six studies were judged to have *probably high* or *high* risk of bias by at least two of the assessment criteria.

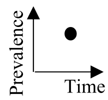
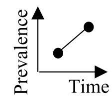
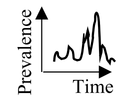
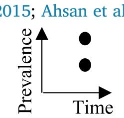
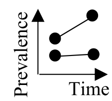
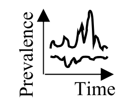
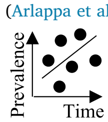
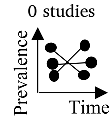
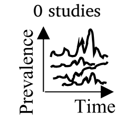
The remaining twelve studies on acute undernutrition provided only single cross-sectional uncontrolled drought-time prevalence estimates. The prevalence of acute undernutrition (weight-for-height index Z-score < -2 Standard Deviations (SD)) ranged from 7% (95% CI 5.9, 9.0%) in a traditionally surplus grain producing area of war affected Afghanistan (Assefa et al., 2001) to 28% during the second year of drought in Timbuktu, Mali (Carnell and Guyon, 1990), reflecting a *poor* to *critical* situation, by the WHO classification (WHO, 2010). Overall, attribution of acute undernutrition to drought exposure was limited.

3.7.2. Chronic undernutrition

Chronic undernutrition (or stunting) reflects effects of insufficient nutrient intake compared to the individual energy needs (which increase with an illness or heavy physical activity) over a longer-term and particularly over the time-period from conception till two years of age. Only one of the eleven studies that reported on stunting had a design that allowed comparing its levels in conditions with and without drought exposure (*probably high* risk of bias). The study suggested a 5.9 percentage point increase in stunting with the drought exposure ($p < 0.001$) in Ethiopia in the presence of food aid and increased child undernutrition screening and treatment efforts (Gari et al., 2017).

The remaining ten studies on chronic undernutrition (or stunting) were based on uncontrolled single cross-sectional prevalence estimates during droughts, mostly indicating a *high* prevalence of stunting, as per

Table 4
Study designs and the strength of evidence they can potentially provide for an association.

Study design	Cross-sectional		Longitudinal[a]
	Single estimate in time	Repeated over time[b]	
No control site	 12 studies (Centers for Disease Control and Prevention, 1991; Assefa et al., 2001; Carnell and Guyon, 1990; De Waal et al., 2006; Katona-Apte and Mokdad, 1998; Mahapatra et al., 2000; Moloney et al., 2011; Renzaho, 2006a; Renzaho, 2006b; Singh et al., 2006; Venkaiah et al., 2015; Ahsan et al., 2017)	 3 studies (Gari et al., 2017; Kumar and Bhawani, 2005; Mude et al., 2009)	 5 studies (Block et al., 2004; Gitau et al., 2005; Lindtjørn, 1990; McDonald et al., 1994; Bauer and Mburu, 2017)
One control site	 1 study (Arlappa et al., 2011)	 0 studies	 0 studies
Multiple sites (with different exposure levels)	 0 studies	 6 studies (Chotard et al., 2010; Kumar et al., 2016; Lazzaroni and Wagner, 2016; Mason et al., 2005Mason et al., 2010a; Mason et al., 2010b)	 0 studies

[a] The same sample of subjects followed up over time.
[b] Two or more cross-sectional studies repeated over time in the same population(-s) with a new sample drawn each time.

the WHO classification (WHO, 2010). The prevalence of stunting (height-for-age index Z-score < -2 SD) ranged from 26% in the Jodhpur district of India (Singh et al., 2006) to 63.7% (95% CI 58.6, 68.8%) in the Kohistan district of Afghanistan (Assefa et al., 2001). Hence, attribution of chronic undernutrition to drought exposure was limited.

3.7.3. Mixed undernutrition

Mixed undernutrition (or the state of being underweight) reflects both acute and chronic causes of undernutrition. Of the fifteen studies on underweight, seven had designs that permitted the examination of its association with drought exposure. Of these, only two studies by Kumar et al. and Lazzaroni & Wagner were judged of *low* or *probably low* risk of bias (by all criteria, except blinding), finding a statistically significant association of drought exposure in the year of birth and year before birth with weight-for-age Z-score (WAZ) in India (Kumar et al., 2016) and almost a quarter of variation in WAZ explained by drought exposure in Senegal (Lazzaroni and Wagner, 2016). The remaining five studies suggested mixed results. Studies in Southern Africa (Mason et al., 2010a) and the Horn of Africa (Mason et al., 2010b) suggested higher levels of underweight in conditions with droughts *vs* without droughts: 24.7% *vs* 21.3% ($p < 0.05$) and 28.0% *vs* 20.4% ($p < 0.05$) across the regions respectively. Studies in Indonesia (Block et al., 2004) and Kenya (McDonald et al., 1994) found no evidence of higher levels of child underweight during droughts, possibly explained by calorie reallocation from mothers to children during the time of food stress. The study in the Tullu district of Ethiopia reported 3.1 percentage point decrease in child underweight during the drought as compared to the preceding year ($p < 0.001$), possibly as a result of an effective food and nutrition intervention implemented during the drought (Gari et al., 2017). These five studies were judged to have (*probably*) *high* risk of bias by two or more criteria.

The remaining eight studies on mixed undernutrition provided only single cross-sectional uncontrolled drought-time prevalence estimates. These studies reported drought-time prevalence of underweight children (WAZ < -2 SD) ranging from 33% in Tharparkar district of Pakistan (Ahsan et al., 2017) to 63.4% in Baran district of Rajasthan, India during the fifth year of drought (Kumar and Bhawani, 2005). According to the WHO (WHO, 2010), these prevalence levels are classified as *high*. Yet, evidence of the *association* between drought exposure and being underweight was only provided by one study with a *low* risk of bias (Kumar et al., 2016).

3.7.4. Micronutrient deficiencies

Studies of micronutrient undernutrition were few (six studies), of which only four were designed to examine its *association* with drought exposure. Only the study by Kumar et al. was judged to have *low* or *probably low* risk of bias (by all criteria except blinding), and suggested that there is evidence for an association between drought exposure in the year before child's birth and a higher prevalence of child anaemia in India (Kumar et al., 2016). A longitudinal study suggested a positive association between anaemia and drought exposure in the year of birth in Indonesia (Block et al., 2004), a cross-sectional study repeated before and during a drought in Ethiopia suggested an increase in the prevalence of anaemia from 28.2% to 36.8% ($p < 0.001$) (Gari et al., 2017), and one study with controlled cross-sectional design suggested greater vitamin A deficiency in severely drought affected *vs* unaffected areas of India (Arlappa et al., 2011). Yet, all three studies were judged to be *probably high* or *high* risk of bias by multiple assessment criteria. The remaining two studies reported only uncontrolled drought-time prevalence of vitamin A, B, and C deficiency (Chotard et al., 2010; Katona-Apte and Mokdad, 1998) in Indian states. Hence, only one study provided high quality evidence for the *association* of drought exposure with increased child anaemia in India.

3.7.5. Other undernutrition outcomes

A correlation of infant length (but not weight) Z-scores (measured at the age of 6 and 16 weeks) with drought-related maize price fluctuation, which the infants were exposed to *in utero*, was found in Lusaka, Zambia (Gitau et al., 2005).

3.7.6. Time course of impacts

Most studies examined undernutrition outcomes during the drought events. Two studies suggested longer-term effects of drought. The study

Table 5
Summary of the results of the risk of bias assessment in individual studies.

Study	exposure assessment	outcome assessment	sampling and recruitment	blinding	confounding	incomplete outcome data	selective reporting	conflict of interest	other bias	migration or survival bias
Ahsan et al., 2017	ph	l	l	ph	n/a	l	l	l	l	ph
Arlappa et al., 2011	pl	ph	pl	ph	h	pl	l	pl	l	ph
Assefa et al., 2001	ph	ph	pl	ph	n/a	pl	l	pl	l	ph
Bauer and Mburu, 2017	pl	l	pl	ph	ph	u	l	l	l	ph
Block et al., 2004	h	pl	pl	ph	h	u	pl	pl	l	pl
Carnell and Guyon, 1990	ph	ph	pl	ph	n/a	l	l	pl	l	ph
CDC, 1991	u	ph	pl	ph	n/a	u	l	pl	l	pl
Chotard et al., 2010	ph	pl	pl	ph	ph	l	l	pl	l	ph
De Waal et al., 2006	pl	u	pl	ph	n/a	u	pl	pl	l	pl
Gari et al., 2017	l	l	l	ph	ph	u	l	l	l	h
Gitau et al., 2005	ph	pl	l	ph	ph	ph	l	l	l	ph
Katona-Apte and Mokdad, 1998	pl	ph	h	ph	n/a	pl	l	ph	l	pl
Kumar and Bhawani, 2005	u	ph	l	ph	n/a	l	l	pl	l	ph
Kumar et al., 2016	l	l	pl	ph	pl	pl	l	l	l	l
Lazzaroni and Wagner, 2016	pl	l	pl	ph	pl	l	pl	l	l	pl
Lindtjørn, 1990	u	pl	u	ph	h	u	l	l	l	ph
Mahapatra et al., 2000	u	ph	pl	ph	n/a	l	l	l	l	pl
Mason et al., 2005	l	pl	pl	ph	ph	u	l	pl	l	l
Mason et al., 2010	l	pl	pl	ph	h	u	l	pl	l	l
Mason et al., 2010	l	pl	pl	ph	h	u	l	pl	l	l
McDonald et al., 1994	ph	pl	ph	ph	ph	ph	l	pl	l	ph
Moloney et al., 2011	u	l	pl	ph	n/a	u	pl	pl	l	ph
Mude et al., 2008	l	pl	ph	ph	h	ph	l	pl	l	pl
Renzaho, 2006a	pl	u	l	ph	n/a	l	l	pl	l	ph
Renzaho, 2006b	l	u	l	ph	n/a	l	l	pl	l	ph
Singh et al., 2006	u	ph	pl	ph	n/a	pl	l	l	l	ph
Venkaiah et al., 2015	pl	ph	pl	ph	n/a	u	h	pl	l	pl

by Kumar et al. (judged to be *low* or *probably low* risk of bias by all criteria except blinding), found that drought exposure at birth, *in utero*, and early life was associated with higher risk of being underweight until 5 years of age, *i.e.*, also after the end of the drought event (Kumar et al., 2016). Furthermore, a study in Indonesia (*high* or *probably high* risk of bias by four criteria) suggested that the compound exposure to a drought and financial crisis led to a decline in child haemoglobin levels not only during the drought and crisis but remained below the pre-crisis level a year after the event (Block et al., 2004).

3.8. Synthesis of findings on suggestive indication for effect modification

Although none of the reviewed studies, except one (Lazzaroni and Wagner, 2016), formally assessed factors that may modify drought effect on child undernutrition, their results suggested that differences in effect might be possible by age at exposure, sex, urban *vs* rural setting, baseline public health situation, and presence of concurrent events or interventions implemented in response to the drought.

3.8.1. Age at exposure and sex

The study by Kumar et al. (*probably low* risk of bias except the criteria of blinding) and another study with *probably high* risk of bias suggested a stronger effect of drought exposure *in utero* than exposure in the year of birth on child haemoglobin levels in India (Kumar et al., 2016) and on infant length in Zambia (Gitau et al., 2005). Another study with *probably high* risk of bias in Kenya suggested that droughts affected nutritional status of schoolchildren and toddlers' caregivers but not toddlers (McDonald et al., 1994). A study in Indonesia with *high* or *probably high* risk of bias by four criteria suggested that compound exposure to a drought and financial crisis affected haemoglobin levels in boys significantly more than in girls (Block et al., 2004).

3.8.2. Urban vs rural setting

The study by Kumar et al. with *probably low* risk of bias (by all

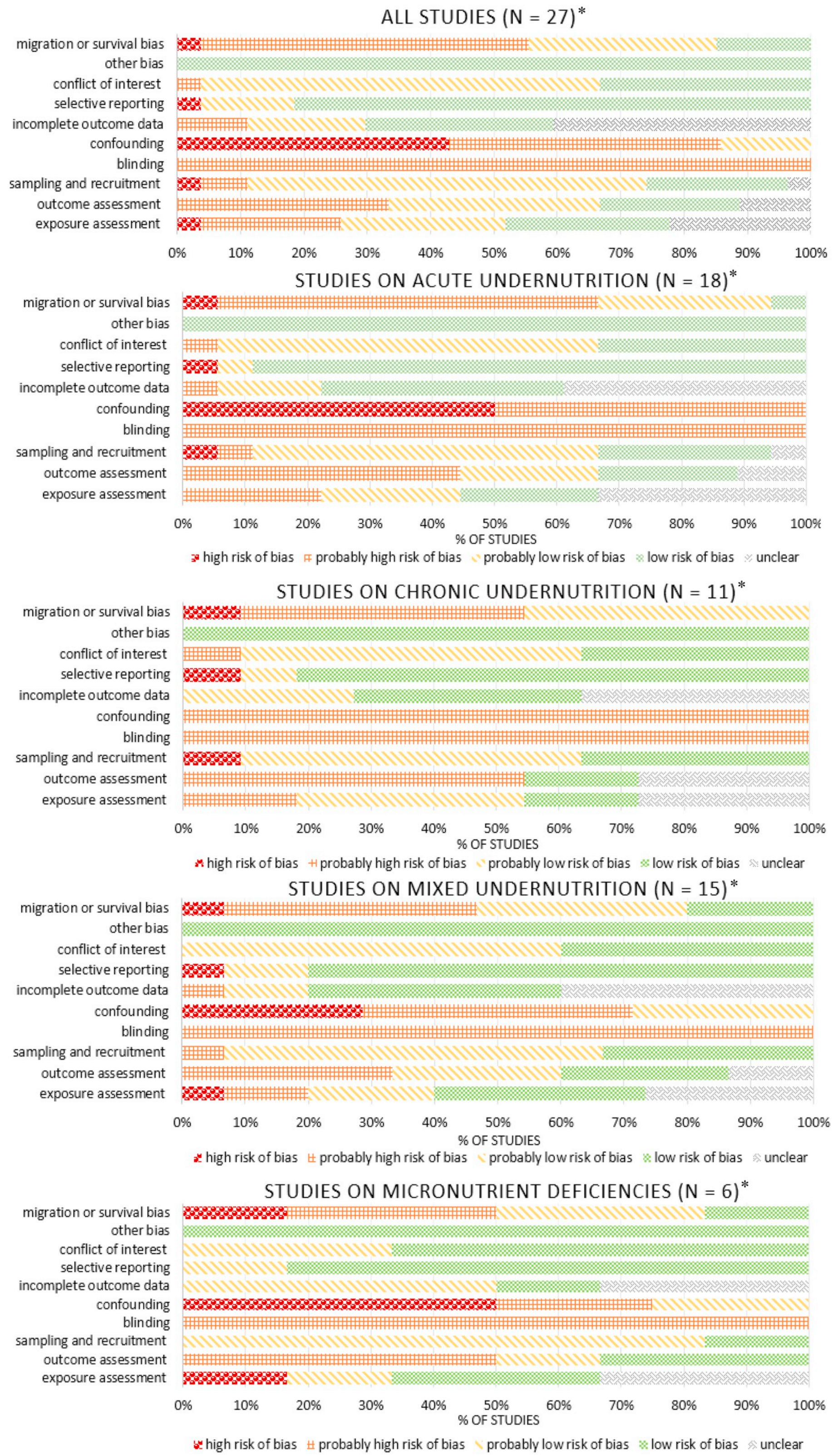


Fig. 2. Synthesis of the risk of bias assessment across studies by type of undernutrition.
*The assessment of confounding was applicable and performed in 14 studies, therefore 100% corresponds to 14 studies in the overall summary, 6 in the summary of studies on acute undernutrition, 1 on chronic undernutrition, 7 on mixed undernutrition, and 4 on micronutrient undernutrition.

criteria except blinding) suggested a lower effect of drought on children being underweight in urban as opposed to rural areas of India (Kumar et al., 2016). By contrast, a study with a *probably high* risk of bias by two criteria observed greater drought-time deterioration in the underweight state of children in areas close to large towns as opposed to rural areas of Southern Africa, which could be linked to lower access to food aid or higher HIV prevalence in areas around towns (Mason et al., 2005).

Table 6
Summary of the assessment of the quality and strength of evidence on drought as a risk factor for four types of child undernutrition in LMICs.

	Acute undernutrition (n = 15)		Chronic undernutrition (n = 9)		Mixed undernutrition (n = 12)		Micronutrient deficiencies (n = 6)	
	Rating	Basis	Rating	Basis	Rating	Basis	Rating	Basis
Quality of evidence assessment								
i. Downgrade considerations								
Risk of bias across studies	−1	There is substantial risk of bias across most studies	−1	There is substantial risk of bias across most studies	0	Among all, one study with large sample judged to have low risk of bias	0	Among all, one study with large sample judged to have low risk of bias
Indirectness	0	Anthropometric measures were appropriate outcomes, studies conducted in the population of interest, mostly direct measures of exposure	−1	Only one study compared drought and non-drought periods directly	0	Anthropometric measures were appropriate outcomes, studies conducted in the population of interest, mostly direct measures of exposure	0	Anaemia was determined by measuring blood haemoglobin levels (however, vit A deficiency was examined using a surrogate measure – count of Bitot's spots), studies conducted in the population of interest, key studies used direct measures of exposure
Inconsistency	0	Effect estimates often not clearly quantified, and variations likely because of differing contexts	0	Effect estimates often not clearly quantified, and variations likely because of differing contexts	0	Effect estimates often not clearly quantified, and variations likely because of differing contexts	0	Effect estimates often not clearly quantified, and variations likely because of differing contexts
Imprecision	0	Mostly based on large surveys, but based on comparison across few settings or years	0	Mostly based on large surveys, but based on comparison across few settings or years	0	Mostly based on large surveys, but based on comparison across few settings or years	0	Mostly based on large surveys, but based on comparison across few settings or years
Publication bias	−1	Most studies examined severe events, not reflective of the full range of drought events occurring	−1	Most studies examined severe events, not reflective of the full range of drought events occurring	0	Severe events examined < 50% of the studies; publication bias possibly insufficient for downgrading	0	Severe events examined in 50% of the studies; publication bias possibly insufficient for downgrading
ii. Upgrade considerations								
Large effect magnitude	1	Effect magnitude was over 2 (but not 5) times increase in the outcome prevalence	0	No effect estimates were available	0	Effect magnitude was below 2 times increase in the outcome prevalence	0	Effect magnitude was below 2 times increase in the outcome prevalence
Dose response	0	Not reported in individual studies. Difficult to compare across studies	0	Not reported in individual studies. Difficult to compare across studies	0	Not reported in individual studies. Difficult to compare across studies	0	Not reported in individual studies. Difficult to compare across studies
Confounding minimises effect	0	No evidence found to suggest that possible residual confounders would reduce effect estimate	0	No evidence found to suggest that possible residual confounders would reduce effect estimate	0	No evidence found to suggest that possible residual confounders would reduce effect estimate	0	No evidence found to suggest that possible residual confounders would reduce effect estimate
iii. Summary of the quality assessment								
Overall quality of evidence start: *moderate*	*Low*	Moderate + (−1) + (−1) + (1) = low. Downgrading/upgrading changed the quality from moderate to low	*Low*	Moderate + (−1) + (−1) + (−1) = low. Downgrading changed the quality from moderate to low	*Moderate*	Moderate + (0) = moderate. There were no upgrades or downgrades to change the quality from the initial rating	*Moderate*	Moderate + (0) = moderate. There were no upgrades or downgrades to change the quality from the initial rating
Summary of findings	n/a	Usually higher prevalence of wasting found during droughts, but not always clear	n/a	Usually prevalence of chronic undernutrition during droughts was high, but not always clear	n/a	Higher risk of being underweight with early life drought exposure	n/a	Higher prevalence of anaemia and vitamin A deficiency found with drought
Strength of evidence assessment								
Quality of evidence	n/a	*Low*	n/a	*Low*	n/a	*Moderate*	n/a	*Moderate*
Direction of effect estimates	n/a	Direction largely as expected (more wasting in drought)	n/a	Direction as expected (more stunting during the drought) but only based on one study	n/a	Direction as expected (more children being underweight in drought) in studies with low risk of bias and mixed in studies with high risk of bias	n/a	Direction as expected (more anaemia/vitamin deficiency in drought)
Confidence in effect estimates	n/a	Effect estimates uncertain, often uncontrolled, and relate to varying contexts. Difficult to compare across studies, therefore. New studies might show different estimates.	n/a	Effect estimates uncertain, often uncontrolled, and relate to varying contexts. Difficult to compare across studies, therefore. New studies might show different estimates.	n/a	Effect estimates uncertain, often uncontrolled, and relate to varying contexts. Difficult to compare across studies, therefore. New studies might show different estimates.	n/a	Effect estimates uncertain, often uncontrolled, and relate to varying contexts. Difficult to compare across studies, therefore. New studies might show different estimates.
Other aspects	n/a							

(*continued on next page*)

Table 6 (*continued*)

	Acute undernutrition (n = 15)		Chronic undernutrition (n = 9)		Mixed undernutrition (n = 12)		Micronutrient deficiencies (n = 6)	
	Rating	Basis	Rating	Basis	Rating	Basis	Rating	Basis
		Drought event characteristics, contextual factors, including population exposure level and vulnerability, any preventative or humanitarian response vary across studies and make interpretation less certain and less clear.						
Overall strength of evidence	*Limited*	Positive association of drought with increased prevalence of acute undernutrition is likely. Lack of rigorous control and comparability across studies means quantitative estimates can be interpreted in only the broadest terms.	*Limited*	Positive association of drought with increased prevalence of chronic undernutrition is likely, however, current evidence is only based on one study. Effect estimates may change with further studies, particularly as different temporal aspects of the association are examined.	*Limited*	Positive association of drought with increased prevalence of mixed undernutrition is likely, however, current evidence is limited and effect estimates may change with further studies, particularly as different temporal aspects of the association are examined.	*Limited*	Positive association of drought with increased prevalence of anaemia, but again difficult to compare studies given variations in context. Effect estimates may change with further studies. Evidence on the effect on other micronutrient deficiencies was limited (vitamin A deficiency) or missing.

3.8.3. Baseline public health situation

The baseline health and nutritional status of the exposed may in part confer their vulnerability to the impacts of drought. Two studies with a (*probably*) *high* risk of bias by two criteria (WHO, 1998; WHO, 2010), suggested a significant interaction of HIV prevalence with the association of drought exposure and the risk of children being underweight in Southern Africa (but not in the Horn of Africa), observing a significant association in areas with high HIV prevalence but not in areas with low HIV prevalence. One of these studies also suggested the possible importance of baseline undernutrition levels, as child nutritional status deteriorated with drought more rapidly in areas with better than areas with worse baseline prevalence of underweight children in Southern Africa (Mason et al., 2005).

3.8.4. Concurrent events

Fifteen studies were conducted in settings where droughts occurred concurrently with other potentially nutritionally-impactful events, such as floods, wildfires, economic shocks, government instability or armed conflicts (Assefa et al., 2001; McDonald et al., 1994; Kumar et al., 2016; Gitau et al., 2005; Block et al., 2004; Chotard et al., 2010; De Waal et al., 2006; Kumar and Bhawani, 2005; Lazzaroni and Wagner, 2016; Mason et al., 2005; Mason et al., 2010b; Moloney et al., 2011; Renzaho, 2006a; Renzaho, 2006b; Singh et al., 2006). Yet, only one study (*probably low* risk of bias) examined the modifying effect of a concurrent event (price shock) on the association of drought exposure with child nutritional status. It suggested that price shock partly mitigated negative effects of droughts on child nutritional status by increasing household incomes from sales of home-produced goods, in the conditions when nutritional programmes were implemented in the study area (Lazzaroni and Wagner, 2016).

3.8.5. Interventions

Four studies mentioned nutritional programmes existing in their study areas prior to the drought (Gitau et al., 2005; Arlappa et al., 2011; Lazzaroni and Wagner, 2016; Venkaiah et al., 2015), and twelve interventions implemented in response to the drought, such as food distribution (Gari et al., 2017; McDonald et al., 1994; De Waal et al., 2006; Kumar and Bhawani, 2005; Lindtjørn, 1990; Renzaho, 2006b; Venkaiah et al., 2015; Ahsan et al., 2017), nutrition (Gari et al., 2017; Carnell and Guyon, 1990; Kumar and Bhawani, 2005; Renzaho, 2006b; Venkaiah et al., 2015), medical care and vaccination (Carnell and Guyon, 1990; Lindtjørn, 1990), or wider economic and food security management (Mason et al., 2010a). Overall, their results suggested variable effectiveness of the interventions in mitigating drought impacts on children's nutritional status. The study by Lazzaroni & Wagner (*probably low* risk of bias except the criteria of blinding) reported an increase in negative effect of drought on children's nutritional status despite an expansion in agricultural and nutrition programmes, which authors explained by the simultaneously increasing severity of the drought (Lazzaroni and Wagner, 2016). A study in India (*probably* high risk of bias) reported a decline in child underweight levels during a drought six months after the implementation of an intervention (nutrition and care centres) (Kumar and Bhawani, 2005). Of the six studies (*probably high* risk of bias) that related drought exposure to child undernutrition in the presence of an intervention, two reported limited evidence of negative drought effect on child undernutrition (Gari et al., 2017; McDonald et al., 1994), nevertheless, four observed a notable deterioration in children's nutritional status with drought (Gitau et al., 2005; Arlappa et al., 2011; Lindtjørn, 1990; Mason et al., 2005). Of the two cross-sectional studies conducted in areas with and without an intervention (*probably high* risk of bias), both suggested that there was no difference in the levels of child undernutrition between the areas with and without the interventions (Carnell and Guyon, 1990; Renzaho, 2006a). The remaining five cross-sectional studies that were conducted in the presence of the interventions reported levels of child undernutrition mostly classifiable as 'very high' or 'critical', according to the WHO classification (WHO, 2010).

4. Discussion

4.1. Summary of findings

Our evidence review of observational studies on undernutrition among children < 5 years of age in relation to periods of drought in LMICs suggests that the evidence base is not sufficiently robust to provide quantitative estimates of attributable impacts. Only two studies, by Kumar et al. and Lazzaroni & Wagner were judged of *low* or *probably low* risk of bias by all criteria of individual study assessment (except the criteria for blinding, which was not implemented by any study), suggesting an adverse effect of early life drought exposure on children being underweight and having anaemia during and after the drought events (Kumar et al., 2016; Lazzaroni and Wagner, 2016). The overall strength of the evidence was judged to be *limited* due to the risk of bias, lack of estimate comparability across studies, and likelihood that further studies could show different results for each type of undernutrition (acute, chronic, mixed, and micronutrient). *Limited* evidence does not suggest that drought exposure is not a risk factor for child undernutrition in LMICs, but reflects the lack of robust research, much of which was undertaken in challenging circumstances for epidemiological surveillance and substantial heterogeneity in contexts.

Nonetheless, these studies are valuable in highlighting the high prevalence of undernutrition in LMICs during the examined drought events across the entire range of years from 1984 to 2015. According to the WHO, these levels require urgent response in the short term (WHO, 2010) but also the development of preventative strategies in the long term. What remains uncertain is the extent to which the observed levels of child undernutrition are attributable to drought exposure as opposed to other contextual factors and concurrent events. Almost all of the study populations examined in the reviewed papers were characterised as vulnerable due to high level of infectious disease, poverty, concurrent impact of other disasters, economic and political instability, or a war. This may suggest that drought in and of itself is never the sole cause of undernutrition, but triggers undernutrition in populations that are already vulnerable. Therefore, interventions that address the underlying vulnerabilities, *e.g.*, investment in development, reduction of the burden of infectious diseases, protection of non-combatants from war, could have high value in strengthening the resilience to the impacts of drought and leveraging overall improvements in child nutritional status.

The two systematic reviews that have been previously conducted on the topic of the health impacts of droughts already emphasized the multiplicity of pathways through which droughts affect human health and discussed the importance of contextual factors as well as the underlying population vulnerability (Alpino et al., 2016; Stanke et al., 2013). They also briefly commented on the variable quality of the available studies on this topic. Our review provided a detailed systematic assessment of the quality and strength of the available peer-reviewed evidence on the impacts of droughts, specifically on child undernutrition in LMICs.

Development of effective preventative response strategies would benefit from robust evidence on the potential magnitude and timing of the drought effects, as well as their modifying factors. The results of our review suggest that drought exposure may be associated with a higher risk of undernutrition not only during the drought but also several years after the event (Kumar et al., 2016). Our findings also suggest possible modification of drought effect by such factors as sex, age, urban *vs* rural setting, baseline health and nutritional status of the exposed, concurrent events, and interventions implemented in response to the drought effects. Most studies suggested that there is scope for the improvement of the effectiveness of intervention programmes, particularly their preventative aspects. This may include combining short-term response interventions with long-term preventative programmes targeting multiple pathways that mediate drought impacts and addressing other sources of vulnerability.

Nevertheless, resources for such programmes are limited, *e.g.*, in sub Saharan Africa only 16% of consolidated appeals for emergencies are funded (Mude et al., 2009). Therefore, further investigation of the modifying influences, based upon methods permitting time-course and effect modification analyses, is required to acquire comprehensive and robust evidence relating to who, when, and where may require targeted support the most. Furthermore, systematic reporting of the presence and absence of contextual factors that might modify drought effect on child nutritional status should be encouraged to permit examining the influence of such factors in future systematic reviews and syntheses.

To facilitate the improvement in the quality and robustness of further studies on this topic, we summarise our identified methodological shortcomings of the reviewed studies and provide corresponding recommendations.

4.2. Identified methodological shortcomings & recommendations

A key limitation of the reviewed studies was the lack of robust study designs that would permit attribution of drought impacts on child undernutrition. The majority of the studies were based upon a single set of cross-sectional data without control. There is a greater potential to provide evidence of the cause–effect association on the part of studies that used a control population or examined several estimates in time, and also by longitudinal studies. However, most of these study designs (with two exceptions (Kumar et al., 2016; Lazzaroni and Wagner, 2016)) did not permit the elimination of substantial risk of confounding to discern the proportion of child undernutrition that was attributable to the drought event as opposed to any potential concurrent events, *e.g.*, war or financial crisis, that could also have had a simultaneous negative effect on child nutrition during the examined drought events. Many of the reviewed studies with these designs had further shortcomings, such as the (almost inevitable) lack of blinding, the limited assessment of possible survival and migration bias, and poor control for confounding, all of which often limited the robustness of their findings. Well-designed studies, based on longitudinal data and which minimise the risk of survival and migration bias whilst comprehensively controlling for confounding, are required.

The robustness and comparability of the reviewed studies was also subject to limitations of outcome assessment methods. The prevalence estimates of child undernutrition could have been underestimated in studies that used the NCHS growth reference in the assessment of anthropometric indices and studies that used clinical signs to detect micronutrient deficiency (de Onis et al., 2006; Wyss, 2004; WHO, 1998). Furthermore, many studies did not report their data quality control and cleaning procedures, which are required for the assessment of the risk of bias. To acquire accurate undernutrition prevalence estimates, future studies should use the WHO Child Growth Standard in the assessment of anthropometric indices (de Onis et al., 2006) and blood sample micronutrient measurements (Wyss, 2004; WHO, 1998), as well as report data quality control and processing procedures.

Furthermore, evidence of the reviewed studies was limited by shortcomings in the exposure assessment methods, particularly the lack of drought definition and exposure justification with data on relevant, direct, and geographically accurate proxy measures of drought. Drought typology ranges from meteorological, agricultural, and hydrological, to socio-economic droughts, which reflects the diversity of their underlying causes (Wilhite and Glantz, 1985). Droughts are slow onset events, which develop over periods of time, and have no visual or structural boundaries with their impacts lasting long after the physical drought conditions are over (Mishra and Singh, 2010). The use of an operational definition of drought which identifies its onset, severity, and termination (Wilhite and Glantz, 1985; Dai, 2011) (*e.g.*, Standardized precipitation index, Palmer drought severity index (Mishra and Singh, 2010; Wilhite and Glantz, 1985; Lloyd-Hughes, 2014), could facilitate analyses of temporal aspects of drought impact and improve the comparability of results across studies.

To inform the design of effective preventative response strategies (*e.g.*, early warning systems), models forecasting the undernutrition impacts of droughts could be explored. Exposure metrics for such models could be selected based on their capacity to predict the undernutrition impact with a lead-time sufficient for response implementation. Only one study included in this review attempted predictive modelling that could be used for the design of a nutrition-focused drought early warning system (Mude et al., 2009).

4.3. Limitations of the review

We did not search for publications in languages other than English nor in grey literature. We estimated the prevalence of literature in other languages by running our searches without the constraint to include articles only in English. The searches only identified 650 records in other languages additionally to the 8029 records we identified in English. Hence, by limiting our searches to articles published in English, we covered 93% of the literature available in all languages. Given the focus of this review on the quality and strength of peer-reviewed evidence, grey literature, which does not undergo peer-review, was not considered eligible for our assessment. Although there is valuable grey literature available on the topic of this review, it is highly unlikely that their inclusion would have changed the overall conclusions and interpretation of our review, as grey literature tends to be of lower quality than the peer-reviewed literature.

5. Conclusion

The strength of evidence on drought as a risk factor for undernutrition among children < 5 years of age in LMICs is *limited*. Nonetheless, studies suggest that there are apparently *high* and *critical* levels of child undernutrition in vulnerable settings during droughts, indicating the need for short-term response, and the development of preventative strategies in the long-term. The latter requires improved evidence of the magnitude of the drought-attributable fraction of child undernutrition, timing of drought impacts, influence of vulnerability and other potential modifying factors, and (in time) intervention studies.

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Declaration of Competing Interest

None.

Authorship

KB conceived the idea and designed the review with advisory input from PW; KB completed literature search, review of records and full text version of the identified papers for inclusion, data extraction, and the assessments of the risk of bias, quality and strength of evidence; RP and MZ reviewed full text versions of the identified papers for inclusion; CA and MZ validated data extraction, and performed the assessment of the risk of bias; PW helped to resolve any disagreement between two reviewers assessing full text papers for inclusion and performing the risk of bias assessment; KB drafted the paper with editorial changes and comments from other authors.

Ethical standards disclosure

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the London School of Hygiene and Tropical Medicine Observational Ethics Committee.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2019.104973.

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