Title: Integrating Climate Services into Health Systems for Nutrition Security: A Scoping Review

Short Title: Climate Services for Nutrition: A Scoping Review

Authors:
Bianca Carducci[1], MSc, PhD (ORCID: 0000-0003-3815-3048)
Georgia Dominguez[2], MSc (ORCID: 0000-0003-3243-4535)
Jessica Fanzo[1], PhD (ORCID: 0000-0002-6760-1359)

Affiliations:

[1] Columbia Climate School, Columbia University, New York, New York, United States
[2] Centre for Global Child Health, The Hospital for Sick Children, Toronto, Ontario, Canada

Corresponding Author: bianca.carducci@alumni.utoronto.ca

Abstract

Climate information services (CIS) are science-based tools used to inform decision-making in climate-sensitive sectors, such as agriculture, water resources, energy, disaster risk reduction and health. These CIS rely on high-quality climate and weather data in order to predict and prepare for specific extreme weather or climate events such as droughts and floods. Within the health sector, most CIS have been developed to prevent and treat specific infectious diseases or food insecurity; however less is known on how CIS have been used for nutrition programming. We conducted a scoping review of available evidence, on the use of CIS to implement nutrition interventions (both direct and indirect health and other sectors) ahead of extreme weather or climate events. We searched PubMed, Web of Science and Scopus, and grey literature sources for primary studies (observational, intervention, and program evaluations) conducted in low- and middle-income countries from January 1, 2000 to April 1, 2024. We included 48 studies, representing 67 country-level programs. The majority of programs were found in the African region (n=38), followed by Region of the Americas (n=9), Western Pacific Region (n=8), Eastern Mediterranean Region (n=1), and the European Region (n=1). Most CIS were developed in response to vector-borne diseases (17 countries), droughts (10 countries), floods (9 countries) or multi-hazards (11 countries). The types of nutrition programs deployed were largely outside of the health sector including poverty alleviation (n=49 programs), water, sanitation and hygiene (n=24 programs), disease prevention (n=23 programs) or emergency nutrition (n=19 programs). Few studies evaluated impacts of CIS on nutritional status in vulnerable populations. There is urgency and opportunity for better integration of weather and climate information into health systems decision-making and workforce preparedness at local levels to improve both short- and long-term nutrition outcomes.

Introduction

Climate change and variability pose significant risks to systems that deliver nutrition, and consequently, population nutrition [1]. In recent decades, an increase in greenhouse gas emissions has triggered extreme weather and climate events (also known as hazards or disasters), including, but not limited to floods, droughts, heat waves, and cold waves [2]. These events have become more intense and frequent in nature, shocking systems that provide food, health, water and social protection, and driving further nutrition inequities within and across communities. In addition to current impacts, projections to 2050, which are largely dependent on modelling assumptions and scenarios, suggest that climate change and variability will have detrimental impacts on nutrition, such as increases in the prevalence of stunting, wasting and micronutrient deficiencies, but these will vary across regions [3, 4]. Because of this, there is a need for global climate and nutrition agendas to align and increase investments in nutrition-focused early warning systems and long-term climate adaptation strategies.

In an effort to catalyze transformational and systemic change, climate information services are critical for fit-for-purpose decision-making. Climate information services are the "transformation of climate-related data (from the past, present or future), together with other relevant information, into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices development and evaluation of solutions and any other services in relation to climate that may be use for the society at large" [5]. The use of climate information services has historically been utilized in sectors such as agriculture, health, insurance, social protection and humanitarian response, to prevent and prepare for climate hazards [6]. For example, there are a number of global initiatives to improve farmers' use of climate information services to implement necessary innovations and interventions ahead of the growing season to prevent significant losses in yields [7]. Additionally, the health sector has utilized climate information services to identify transmission and infection patterns of vector-borne diseases such as malaria, dengue, zika virus and Lyme disease, in order to develop prevention and control measures [8].

Importantly, the production of climate information services relies on robust, accurate and timely weather and climate data. This includes the temporal and spatial resolution, spatial coverage, accessibility (sharing of observations) and availability in real-time of data [9]. Together, these data can be packaged into services such as weather forecasts (produced up to 14 days in advance), sub-seasonal forecasts (between 3-12 weeks in advance), seasonal forecasts (3-12 months in advance) and climate forecasts (for years, decades and centuries in advance) for early warning and adaptation [10, 11]. Most health systems decisions are made at seasonal to annual timescales and therefore must be matched with weather and climate timescales to be valuable [9]. For public health nutrition practitioners working within health facilities and communities, weather forecasts and early warning systems (at sub-seasonal and seasonal timescales) would be most useful in ensuring resources are available (i.e., stockpiles of therapeutics, capacity of health workforce), as well as, targeting vulnerable populations with preventative nutrition interventions. However, because malnutrition is both a cause and consequence for other diseases, such as infectious diseases, nutrition interventions are often delivered through multi-sectoral approaches [12]. Until now, national meteorological and hydrological agencies have mostly operated separately from ministries and organizations that deliver nutrition.

To address this gap, there is a need to understand what climate information services currently exist to prepare public health nutrition practitioners, how these could be strengthened and tailored for specific climate hazards and more effectively linked to the delivery of essential nutrition interventions. To our knowledge, no synthesis exists at the intersection of climate and nutrition in this manner and therefore a scoping review is most appropriate to explore current evidence, provide direction to future research priorities and implications to policy and practice. The aim of this scoping review is to identify country-level efforts that have integrated climate information services as an adaptation for nutrition programming. More specifically, the objectives of this review are to:

1. Identify current country examples of climate information services into health systems decision-making process for nutrition program delivery within health facilities and communities;

2. Propose direct and indirect health system nutrition intervention packages that help to improve short-term targeting and timing; and
3. Suggest recommendations that inform national and regional health strategies and investments for long-term nutrition adaptation planning and preparedness.

Methods

Conceptual Framing

To guide the selection of studies, we developed a conceptual framework that illustrates how climate information services may be used to inform nutrition programming (Fig 1). The conceptual framework is made up of four stages connected by four elements (integration, investment, implementation and insights). Stage 1 includes using climate information to develop, strengthen and utilize climate information services that are relevant for nutrition. Stage 2 *integrates* climate information services into nutrition decision-making, including identifying direct and indirect health or other sectoral interventions affecting nutrition as illustrated by Keats and colleagues [13]. Direct health-care sector nutritional interventions include food and micronutrient supplementation, breastfeeding support, complementary feeding, treatment and management of acute malnutrition, anaemia treatment, and promotion of healthy diet and physical activity during childhood and adolescence. Indirect health-care sector nutritional interventions were considered family planning and reproductive health services, disease prevention and management strategies (including infectious, vector-borne, and water-borne diseases), and maternal mental health support. Other sectoral strategies directly affecting nutrition include fortification (staple foods, condiments, and agronomic), nutritional interventions in schools, nutrition in emergency programmes, mass and social media messaging, policies to reduce prices or increase access to nutritious and diverse foods, policies limiting marketing of unhealthy foods and breast milk substitutes, and promotion of healthy diets and age-appropriate complementary feeding in social protection programmes. Other sectoral strategies indirectly affecting nutrition include efforts to ensure household food security, poverty alleviation strategies, women's empowerment, child protection and support services, universal education with a gender focus, early child stimulation, water, sanitation and hygiene, food safety

and sugar-sweetened beverage taxes. Stage 3 *scales-up investments* to develop adaptation plans of key essential nutrition interventions and key actions across the building blocks for nutrition, which are adapted from the operational framework for climate resilient and low carbon health systems illustrated by the World Health Organization (WHO) [14]. Stage 4 *implements* these plans, monitors and evaluates the effectiveness of these interventions and provides *insights* to refine climate information services.

Search Strategy

The proposed scoping review was conducted in accordance with the Joanna Briggs Institute methodology for scoping reviews. The search strategy aimed to locate both published and unpublished studies. An initial limited search of PubMed, Web of Science and Scopus was undertaken to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a full search strategy for (Supplementary Tables 1.1-1.3). The search strategy, including all identified keywords and index terms, and was adapted for each included database and/or information source. The reference list of all included sources of evidence was screened for additional studies. Studies published in any language and published since January 1, 2000 until April 1, 2024 were included.

Unpublished Studies and grey literature were searched from the following sources: Alliance for Transformation Action on Climate and Health; Asian Development Bank; Emergency Nutrition Network; High Level Panel of Experts on Food Security and Nutrition; Intergovernmental Panel on Climate Change; International Initiative for Impact Evaluation; Lancet Countdown to Climate and Health (2016-2023); Stronger Foundations for Nutrition; World Bank Open Knowledge Repository; World Health Organizations; SPEI Global Drought Monitor & Laboratory of Climate Services and Climatology; Famine Early Warning Systems Network; Intergovernmental Authority on Development Climate Predication and Applications Centre; and World Food Programme (WFP).

Eligibility Criteria

We included studies or reports where the implementation of nutrition policies and/or programming was informed by climate services. Therefore, only studies which completed all four stages of our conceptual framework were included in this review. Studies were excluded if no climate service was mentioned explicitly or the application of these services for nutrition were planned, but never executed. We included vulnerable population groups that have been targeted by nutrition policies and/or received any nutrition programming informed by climate services. These included women of reproductive age, pregnant and lactating women, children under-5 years, school-aged children and adolescents. In addition, we included studies that examined the use of climate information services to inform nutrition policies and programming implemented in low- and middle-income countries (LMICs), as defined by the World Bank Group [15]. Regional classifications followed the WHO's criteria [16]. We considered randomized controlled trials, quasi-experimental studies, descriptive observational study designs including ecological, case series, individual case reports and descriptive cross-sectional studies for inclusion. Qualitative studies were also considered that focus on qualitative data including, but not limited to, designs such as qualitative description, and action research. Modelling studies, commentaries, viewpoints, abstracts, conference proceedings were excluded.

Study Selection

Following the search, all identified citations were collated and uploaded into Covidence and duplicates removed. Titles and abstracts were screened by one or more independent reviewers for assessment against the inclusion criteria for the review. The full texts of selected citations were assessed in detail against the inclusion criteria by one or more independent reviewers. Reasons for exclusion of sources of evidence at full text that did not meet the inclusion criteria were recorded and reported in the scoping review. The results of the search and the study inclusion process were reported in full in the final scoping review and presented in a Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for scoping review flow diagram (Fig 2).

Data Extraction

Data was extracted from papers by one or more independent reviewers using a data extraction tool developed by the reviewers. The data extracted included specific details about the participants, concept, context, study methods and key findings relevant to the review question/s (Supplemental File). Any disagreements that arose between the reviewers was resolved through discussion, or with an additional reviewer/s.

Data Analysis

The charted data was analyzed descriptively, using tabulations or graphs where appropriate, in order to present a synthesis of key findings according to the scoping review objectives. The narrative synthesis of the extracted data was based on a number of characteristics, including geographic location of studies, types of climate adaptation approaches and entry points for nutrition. Findings were organized to align with the four major classifications and their respective interventions outlined in the Keats and colleagues framework for effective nutrition interventions [17], which were namely 1) direct health-care sector nutritional interventions, 2) indirect health-care sector nutritional interventions, 3) other sectoral strategies directly affecting nutrition, and 4) other sectoral strategies indirectly affecting nutrition. Although this framework currently does not include education and infrastructure, we included these under other sectoral strategies indirectly affecting nutrition given our findings indicated these programs shared similar intentions to improve nutrition outcomes among affected populations from alternative, non-health-care sectors. Country-level programs which included multiple interventions from across the four classifications were considered multi-component. We followed PRISMA-ScR guidelines to report our findings.

Results

The search retrieved a total of 12,657 records, which comprised of 6,908 peer-reviewed, 5,721 grey literature, and 28 from reference snowballing. A total of 1,907 duplicate records were removed and 5,001 records underwent title and abstract screening for articles from databases while 5,749 grey literature documents were retrieved. Among the peer-reviewed records, only

179 were eligible for full-text screening, whereby 169 records were ultimately excluded due to wrong intervention (no climate services) (n=88), wrong study design (not experimental or observational) (n=44), wrong outcomes (no nutrition or health policy, program, or intervention) (n=34), and wrong setting (not from LMICs) (n=3). Among the grey literature records, only 194 were assessed for eligibility, whereby 156 records were excluded due to wrong intervention (no climate services) (n=107) and wrong outcomes (no nutrition or health policy, program, or intervention) (n=49). A total of 48 records (10 peer-review and 38 grey literature) were included in this review, which represent a total of 67 country-level programs [8, 18-64].

Study design and population

The majority of included studies were program descriptions, without evaluations (n=25), while the remaining were program evaluations (n=5), observational, such as cross-sectional and cohort studies (n=7), quasi-experimental (n=3), and one review which compiled datasets from surveys, field observations, and prior research to evaluate the implementation and effectiveness of a program. These studies lacked both quantitative and qualitative data, which prevented any formal meta- or thematic analysis from being conducted.

Study settings

Most studies used climate-information to inform country-level nutrition and health programs in the African Region (n=38). The remaining studies discussed initiatives in the following regions: South-East Asian Region (n=10), Region of the Americas (n=9), Western Pacific Region (n=8), Eastern Mediterranean Region (n=1), and the European Region (n=1). A total of 37 different countries were represented within these regions and most studies discussed initiatives in Bangladesh (n=7), Somalia (n=6), and Madagascar (n=5).

Types of climate information services

Table 1 provides a summary of the various types of climate information services used to prepare for particular climate-related hazards, namely floods, drought, heatwaves, cold waves, storms

(i.e., cyclones, hurricanes), and other (i.e., landslides and vector-borne diseases) by country. Climate information services which have been used monitor and forecast multiple climate-related hazards are also included. It is important to note that identifying forecast timescales used for these climate services proved difficult as some program records were unclear with the scope and frequency by which climate information was utilized to inform a particular nutrition policy and/or program. However, we indicate the most implied timescales used for each hazard below.

299 **Table 1. Climate-Informed Nutrition Programs by Country**
300

Country (Year of Program Implementation)	Climate Event (Forecast Timescale)	Climate Information Service (Level of Implementation)	Program Name (Key Nutrition Actors)	Program Component(s)
Bangladesh (2014, 2020, 2023, 2024) [24, 35, 43, 44, 48, 52, 55]	Floods (short-term to sub-seasonal)	Bangladesh Flood Forecasting and Warning Centre (FFWC) (National)	Anticipatory Action, Forecast-based Financing (WFP and IFRC)	Household food security; poverty alleviation; WASH
		Government of Bangladesh's Early Warning System (National)	Anticipatory Action, Forecast-based Financing (WFP)	Poverty alleviation
		Bahadurabad Gauging Station Forecast Models (Local)	Anticipatory Action (UN, WFP, IFRC, and Bangladesh Red Crescent Society)	Poverty alleviation; WASH
		The Bangladesh Meteorological Department (BMD), the European Centre for Medium-Range Weather Forecasts (ECMWF), and the Global Forecast System (GFS) (Global, regional, national)	Anticipatory Action (WFP)	Poverty alleviation
		Global Flood Awareness System (GloFAS) and Flood Forecasting and Warning Center (FFWC) (Global)	Anticipatory Action (WFP)	Family planning and reproductive health services; Poverty alleviation; WASH
	Multi-Hazard - floods and drought (sub-seasonal and seasonal)	Global Flood and Drought Monitor (Global)	Food for Peace and SHOUHARDO II Program (CARE Bangladesh)	Disease prevention and management; Nutrition in emergencies; Household food security; poverty alleviation; women's empowerment; infrastructure
	Multi-hazard - floods and storms (cyclones) (all time-scales)	Bangladesh Meteorological Department (BMD) (National)	Anticipatory Action (WFP)	Poverty alleviation
Barbados (NR) [25]	Other – arbovirus (seasonal)	Caribbean Institute for Meteorology and Hydrology (CIMH), the technical arm of the Caribbean Meteorological Organization (CMO) (Regional)	Arbovirus Control Program	Disease prevention and management; WASH; education
Botswana (2006) [8]	Other – malaria (seasonal)	Malaria early warning system (MEWS) (national)	Roll Back Malaria Partnerships and National Malaria Control Programme	Disease prevention and management (malaria)
Burundi (2023) [44, 46, 60]	Floods (short-term)	Burundi Hydrometeorological Department (known in French as Institut Géographique du Burundi (IGEBU)) (National)	Anticipatory Action (WFP, Burundi Red Cross)	Poverty alleviation
	Multi-Hazard - floods and drought (all time-scales)	Geographical Institute of Burundi (known in French as Institut Géographique du Burundi or IGEBU) and the Inter-Governmental Authority on Development	Anticipatory Action (WFP)	Poverty alleviation

		(IGAD) Climate Prediction and Applications Centre (ICPAC) (Regional, national)		
Cambodia (2011, 2020-2021) [32, 49, 64]	Other - vector-borne disease (seasonal)	Department of Preventive Medicine, Ministry of Health (DPM) (National)	Vector Control Program	Disease prevention and management
	Multi-hazard - floods and storms	WFP's Platform for Real-time Impact and Situation Monitoring (PRISM) (Global)	Anticipatory Action (WFP)	Poverty alleviation
Chad (2019-2023) [20]	Other – malaria (short-term)	NASA Geospatial Interactive Online Visualization ANd aNalysis Infrastructure (GIOVANNI) (Global)	National Strategic Plans (PSN) + Seasonal Malaria Chemoprevention (SMC) Program	Disease prevention and management
Dominica (NR) [25]	Other – arbovirus (seasonal)	Caribbean Institute for Meteorology and Hydrology (CIMH), the technical arm of the Caribbean Meteorological Organization (CMO) (Regional)	Arbovirus Control Program	Disease prevention and management; WASH; education
Dominican Republic (2022) [38]	Multi-hazard - floods and storms-cyclones (all time-scales)	National Meteorological Office (known in Spanish as Oficina Nacional de Meteorología or ONAMET) and the National Institute of Hydraulic Resources (known in Spanish as Instituto Nacional de Recursos Hidráulicos or INDHRI) (National)	Anticipatory Action (WFP)	Poverty alleviation
Ethiopia (2010, 2016, 2021, 2022) [26, 37, 38, 50, 62, 63]	Drought (all time-scales)	Climate Information and Assets for Resilience in Ethiopia (CIARE) via Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED), National Meteorology Agency (National)	Productive Safety Net Programme (PSNP) (National Meterology Agency, Met Office (UK), Action Aid Ethiopia, Chistian Aid, BBC Media Action, King's College London)	Nutrition in emergency programmes; Household food security; poverty alleviation; WASH
		The Somali Region Disaster Risk Management Bureau (SRDRMB), and the Ethiopian Meteorological Institute (EMI) (National)	Anticipatory Action, Forecast-based Financing (WFP Ethiopia)	Poverty alleviation
		Ethiopian Meteorological Institute (EMI) (National)	Anticipatory Action (WFP)	Poverty alleviation; WASH
	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services (ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management
Fiji (2007, 2023) [19, 47]	Storms – cyclones (short-term)	Fiji National Disaster Management Office (NDMO) (National)	Sexual and Reproductive Health in Crisis and Post-Crisis Situations (SPRINT) Initiative & Minimum Initial Service Package (MISP) for Sexual and Reproductive Health in Crisis Situations	Family planning & reproductive health services; disease prevention and management; mental health support; WASH
		Fiji Meteorological Service and Nadi's Regional Specialised Meteorological Centre (RSMC) (National)	Anticipatory Action (WFP Fiji)	Poverty alleviation
Ghana (2010) [26]	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management

		(ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)		
Guatemala (2023) [42, 44]	Drought (all time-scales)	National Meteorological Agency of the Government of Guatemala (INSIVUMEH) and FEWSNET (Global and National)	Anticipatory Action (WFP)	Poverty alleviation; WASH
		National Institute of Seismology, Volcanology, Meteorology and Hydrology (known in Spanish as the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología or INSIVUMEH) (National)	Anticipatory Action (WFP)	Nutrition in emergency programmes; Poverty alleviation; education
Haiti (2023) [39, 44]	Floods (all time-scales)	Government of Haiti (National)	Anticipatory Action (WFP)	Poverty alleviation
	Multi-Hazard - floods, storms-cyclones (all time-scales)	National Hydrometeorological Service (known in French as Unité Hydro-Météorologique d'Haïti or UHM) (National)	Anticipatory Action (WFP)	Poverty alleviation
Kenya (2016) [21, 29]	Drought (sub-seasonal to seasonal)	Ending Drought Emergency (EDE) and the National Drought Management Authority (NDMA) (National)	High impact nutrition interventions (HINI) and Surge Program (Emergency Nutrition Network)	Treatment and management of acute malnutrition; food supplementation; Health services; Nutrition in emergency programmes; Household food security; poverty alleviation; education
		Famine Early Warning Systems Network (FEWS NET) (Global)	Food For Peace (FFP) Response	Treatment and management of acute malnutrition; food supplementation; Nutrition in emergency programmes; Household food security; poverty alleviation
Kyrgyz Republic (2017) [28]	Other – landslides (all time-scales	Ministry of Emergency Situation's (MES) Department for Monitoring and Forecasting (National)	National-level State System for Civil Protection (SSCP) (Asian Development Bank)	Nutrition in emergency programs; poverty alleviation; infrastructure; education
Lesotho (2011, 2023) [30, 41, 44]	Floods (all time-scales)	National Early Warning Unit (NEWU) (National)	Post-Disaster National Emergency Response (United Nations)	Disease management; Nutrition in emergency programs; Poverty alleviation; WASH; education
	Drought (sub-seasonal to seasonal)	Lesotho Meteorological Services (LMS) (National)	Anticipatory Action (WFP)	Poverty alleviation; WASH
		Lesotho Meteorological Services (LMS) (National)	Anticipatory Action (WFP)	Poverty alleviation
Madagascar (2010, 2017, 2022, 2023) [26, 33, 38, 41, 44, 51]	Drought (all time-scales)	Information System on Food Security and Vulnerability (SISAV), Crop and Food Security Assessment Mission (CFSAM) and the Integrated Phase Classification (IPC) (National and Global)	Early Warning, Early Action (FAO)	Poverty alleviation
		National Disaster Management Agency (known in French as Bureau National de Gestion des Risques et des Catastrophes or BNGRC) and National	Anticipatory Action (WFP)	Poverty alleviation

		meteorological agency (known in French as Direction Général de la Météorologie or DGM) (National)		
		General Direction of Meteorology (Direction Générale de la Météorologie – DGM) (National)	Anticipatory Action (WFP)	Poverty alleviation; WASH
	Multi-Hazard - drought and storms-cyclones (all time-scales)	National Meteorological Agency (known in French as Direction Generale de la Meteorologie or DGM) (National)	Anticipatory Action (WFP)	Poverty alleviation
	Multi-Hazard - floods, droughts, heatwaves, storms (seasonal)	Multi-hazard early warning system (MHEWS) (National)	Disaster Response (Malagasy Red Cross)	Disease prevention and management; Nutrition in emergency programmes; Poverty alleviation; WASH; infrastructure
	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services (ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management
Malawi (2018, 2023) [33, 56]	Floods (Seasonal)	Unspecified Local Government Agencies (Local)	Anticipatory Action (WFP)	Disease prevention and management
	Multi-Hazard - floods, droughts, heatwaves, storms (seasonal)	Multi-hazard early warning system (MHEWS) (National)	Disaster Response (Government's Department of Climate Change and Meteorological Services, Malawi Red Cross Society, and Danish Red Cross)	Disease prevention and management; Nutrition in emergency programmes; Poverty alleviation; WASH; infrastructure
Mali (2010) [26]	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services (ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management
Mongolia (2011, 2016-2017) [49, 53, 64]	Cold waves – dzud (seasonal)	National Agency for Meteorology and Environmental Monitoring (NAMEM) (National)	Forecast-based Financing and Early Warning, Early Action (Red Cross, Red Crescent, FAO)	Nutrition in emergency programmes; Poverty alleviation
	Other - vector-borne disease (seasonal)	National Centre of Infectious Diseases with Natural Foci, Ministry of Health (NCIDNF) (National)	Vector Control Program	Disease prevention and management
Mozambique (2018-2019, 2023) [33, 34, 41, 44, 59]	Drought (sub-seasonal to seasonal)	National Early Warning System via National Disaster Risk Management institute (INGD), the National Meteorological Institute (INAM) and the Ministry of Agriculture (MADER) (National)	Cash Transfer Program (WFP and HelpAge International)	Poverty alleviation
		European Centre for Medium-Range Weather Forecasts (ECMWF) (Regional)	Anticipatory Action (National Institute for Disaster Management and Risk Reduction (Instituto Nacional de Gestão e Redução do Risco de Desastres -INGD))	Poverty alleviation; WASH
	Multi-Hazard - floods, droughts, heatwaves, storms (seasonal)	Multi-hazard early warning system (MHEWS)	Disaster Response (National Institute for Disaster Risk Management and Reduction and WFP)	Disease prevention and management; Nutrition in emergency programmes; Poverty alleviation; WASH;

				infrastructure
	Multi-Hazard - floods, drought, storms-cyclones (all time-scales)	National Institute of Meteorology (known in Portuguese as Instituto Nacional de Meteorologia or INAM), Water Resources Management Directorate (known in Portuguese as Direcção Nacional de Gestão de Recursos Hídricos or DNGRH) and South African Weather Services (SAWS) (Regional, National)	Anticipatory Action (WFP)	Poverty alleviation
Namibia (2006) [8]	Other – malaria (seasonal)	Malaria early warning system (MEWS) (national)	Roll Back Malaria Partnerships and National Malaria Control Programme	Disease prevention and management (malaria)
Nepal (2022) [38, 45]	Floods (all time-scales)	Department of Hydrology and Meteorology (DHM) and OCHA Centre for Humanitarian Data (National)	Anticipatory Action (WFP)	Poverty alleviation
		Climate Risk Index (Global)	Anticipatory Action, Forecast-based Financing (WFP, UN Women, UNFPA, UNRCO, CERF, GFFO)	Family planning and reproductive health; mental health support; Nutrition in emergency programmes; Poverty alleviation
Nicaragua (NR) [50]	Drought (seasonal)	Centro Humboldt (Regional)	Participatory Vulnerability and Capacity Assessments (PVCA) Action Plans	Nutrition in emergency programmes; Household food security; poverty alleviation; WASH
Niger (2022) [38]	Drought (all time-scales)	National Meteorological Services (known as Direction de la Météorologie Nationale du Niger or DMN) and the Agrhymet Regional Centre (known in French as Centre Régional Agrhymet or CRA) (Regional, National)	Anticipatory Action (WFP)	Poverty alleviation; WASH
Pakistan (2015) [27]	Floods (All time-scales)	Pakistan Meteorological Department (PMD) (National)	Basic Humanitarian Package as part of the Responding to Natural Disasters in Pakistan (2015– 2019) program (ACTED)	Nutrition in emergency programs; Poverty alleviation; WASH
Papua New Guinea (2011) [49, 64]	Other - vector-borne disease (seasonal)	National Department of Health (NDOH) (National)	Vector Control Program	Disease prevention and management
Peru (2012) [18]	Cold waves (short-term)	Peruvian Hydrological and Meteorological Service (SENAMHI) (National)	Forecast-based Financing (FbF) via Early Action Protocol (EAP) (Peruvian Red Cross and German Red Cross)	Household food security; poverty alleviation
Rwanda (2005, 2010) [22, 26]	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services (ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management
	Multi-Hazard - floods and drought (all time-scales)	Meteorological Department in the Rwanda Ministry of Natural Resources (National)	Partners in Health (PIH) Catchment	Disease prevention and management; nutrition in emergency programmes; Poverty alleviation, WASH; infrastructure, education,

Somalia (2017, 2020, 2022, 2023) [21, 31, 38, 40, 44, 46, 57, 58, 61]	Floods (short-term)	Global Horn of Africa Climate Outlook Forecast (GHACOF), the Somalia Water and Land Information Management's Flood and Response Information Management System (SWALIM-FRRIMS), the Geospatial Streamflow Forecast Model (GeoSFM) run by the IGAD Climate Prediction and Application Center (ICPAC) (Regional, national)	Flood Anticipatory Action (Somalia Disaster Management Agency)	Treatment and management of acute malnutrition; maternal and child food supplementation; food fortification; nutrition in emergency programmes; poverty alleviation; education
	Drought (sub-seasonal to seasonal)	Famine Early Warning Systems Network (FEWS NET) (Global)	Food For Peace (FFP) Response	Treatment and management of acute malnutrition; food supplementation; Nutrition in emergency programmes; Household food security; poverty alleviation
		European Centre for Medium-Range Weather Forecasts (ECMWF) (Regional)	Anticipatory Action (WFP)	Poverty alleviation
		Famine Early Warning Systems Network (FEWS NET) (Global)	Humanitarian assistance (unspecified)	Micronutrient supplementation; Disease prevention and management (measles, cholera, infections); Nutrition in emergency programmes; Household food security; poverty alleviation
	Multi-Hazard - floods and drought (all time-scales)	Geospatial Streamflow Forecast Model (GeoSFM), run by the IGAD Climate Prediction and Application Center (Regional)	Anticipatory Action via Baxnaano National Safety Net (WFP)	Treatment and management of acute malnutrition; maternal and child food supplementation; nutrition in emergency programmes; nutrition in schools; poverty alleviation
		Somalia Water and Land Information Management's Flood and Response Information Management System (SWALIM – FRRIMS) and the Geospatial Streamflow Forecast Model (GeoSFM) run by the Inter-Governmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC) (Regional, national)	Anticipatory Action (WFP)	Treatment and management of acute malnutrition; nutrition in emergency programmes; poverty alleviation
South Africa (2006) [8]	Other – malaria (seasonal)	Malaria early warning system (MEWS) (national)	Roll Back Malaria Partnerships and National Malaria Control Programme	Disease prevention and management (malaria); education
Tanzania (2010) [26]	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services (ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management
Timor-Leste (2023) [33]	Multi-Hazard - floods, droughts, heatwaves, storms (seasonal)	Multi-hazard early warning system (MHEWS) (National)	Forecast-based Financing (FAO and Red Cross Climate Centre)	Poverty alleviation

Tonga (2007) [19]	Storms – cyclones (sub-seasonal to seasonal)	National Disaster Council (NDC) (National)	Sexual and Reproductive Health in Crisis and Post-Crisis Situations (SPRINT) Initiative & Minimum Initial Service Package (MISP) for Sexual and Reproductive Health in Crisis Situations	Family planning & reproductive health services; disease prevention and management; mental health support; WASH
Uganda (NR, 2009) [23, 54]	Floods (short-term)	Global Flood Awareness System (GloFAS) and the European Commission and the European Centre for Medium-Range Weather Forecasts (ECMWF) (Global and Regional	Anticipatory Action - Forecast-based Financing (German Red Cross and Uganda Red Cross)	Disease prevention and management (diarrhea)
	Other – malaria (short-term and sub-seasonal)	Uganda National Meteorological Authority (National)	National Malaria Control Programme	Disease prevention and management
Zambia (2010) [26]	Other – malaria (sub-seasonal to seasonal)	National Meteorological and Hydrological Services through the Enhancing National Climate Services (ENACTS) initiative and the Climate Prediction Center (CMAP) (Regional)	Roll Back Malaria (RBM) Partnership, including National Malaria Control Programs	Disease prevention and management
Zimbabwe (2006, 2021, 2023) [8, 36, 41, 44]	Drought (sub-seasonal to seasonal)	European Centre for Medium-Range Weather Forecasts (ECMWF) and the Meteorological Services Department (MSD) of Zimbabwe	Anticipatory Action (WFP)	WASH; education; infrastructure
	Other – malaria (seasonal)	Malaria early warning system (MEWS) (National)	Roll Back Malaria Partnerships and National Malaria Control Programme	Disease prevention and management (malaria)
	Multi-Hazard - floods and drought (all time-scales)	Zimbabwe Meteorological Services Department (MSD) (National)	Anticipatory Action (WFP)	Poverty alleviation; WASH

Out of all hazards, most climate information services were specifically used sub-seasonal to seasonal forecasts for vector-borne diseases, such as malaria and other arboviruses, across 17 countries (Barbados, Botswana, Cambodia, Chad, Dominica, Ethiopia, Ghana, Madagascar, Mali, Mongolia, Namibia, Papua New Guinea, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe. Drought-specific services (sub-seasonal to seasonal timescales) were identified in 10 countries (Ethiopia, Guatemala, Kenya, Lesotho, Madagascar, Mozambique, Nicaragua, Niger, Somalia, and Zimbabwe). Flood-specific services were identified in 9 countries (Bangladesh, Burundi, Haiti, Lesotho, Malawi, Nepal, Pakistan, Somalia, and Uganda). Storm-specific services were found in 2 countries (Fiji and Tonga). Cold waves-specific services were also found in 2 countries (Mongolia and Peru). Interestingly, short-term forecast timescales were usually used to inform programming, most likely attributed to anticipated weather-related changes forecasted ahead of these hazards. Only one landslide-specific service was found in the Kyrgyz Republic, although landslides were mentioned in multi-hazard services in 4 countries (Madagascar, Malawi, Mozambique, and Timor-Leste). All forecast timescales (i.e., short-term, sub-seasonal, seasonal) were implied to be utilized for all related services. Likewise, no heat-specific services used in conjunction with nutrition policies and/or programming were found in any studies from LMICs, although heatwaves were explicitly included in the same multi-hazard services.

Multi-hazard services were found in 11 countries (Bangladesh, Burundi, Cambodia, Dominican Republic, Haiti, Madagascar, Malawi, Mozambique, Rwanda, Somalia, Timor-Leste, Zimbabwe). The most common hazards monitored in combination at the country-level were floods and droughts (n=4) (Bangladesh, Burundi, Rwanda, Somalia, and Zimbabwe); floods and storms (n=4) (Bangladesh, Cambodia, Dominican Republic, and Haiti); and floods, landslides, droughts, heatwaves, and storms (n=4) (Madagascar, Mozambique, Malawi, Timor-Leste). The remaining hazard combinations were also found at the country-level in different records: droughts and storms (n=1) (Madagascar) and floods, droughts, and storms (n=1) (Mozambique). As hypothesized, multi-hazard services often use all timescales to anticipate climate events and inform nutrition programming.

It is important to note that identifying forecast timescales used for these climate services proved difficult as some program records were unclear with the scope and frequency by which climate information was utilized to inform a particular nutrition policy and/or program. However, we indicate the most implied timescales used for each hazard in Table 1. The most common timescales were seasonal (n=20) and all (i.e., short-term, sub-seasonal, seasonal) (n=20). Seasonal timescales were mostly used for services informing vector-born disease programs whose interventions were often implemented based on perceived seasonal changes to susceptibility and transmission. In contrast, the use of all timescales was often part of multi-hazard services which needed to account for various climate events. Short-term forecasts (n=12) were also identified, primarily to relay weather-related information (i.e. days in advance) ahead of floods, storms and cold waves. Timescale ranges were also found for short to sub-seasonal forecasts (n=2) and sub-seasonal to seasonal (n=7) forecasts, primarily to analyze multilayered indices for droughts. No timescale information could be confirmed for the remaining six country-level programs.

Climate-informed nutrition and health programs

Of the 67 country-level programs, 42 were single-component [8, 18, 20, 23, 26, 32-35, 37-39, 41-44, 46, 47, 49, 51, 52, 54-56] and 25 were multi-component [8, 19, 21, 22, 24, 25, 27-31, 33, 40, 44-46, 48, 50, 53] nutrition programs (Fig 3). Only 14 country-level nutrition and health programs [20, 22-24, 29-31, 40, 44-46, 50] explicitly indicated a focus on women and children, while the remaining programs were more generalized and implemented among populations impacted by climate-related hazards.

Single-component programs

Among the single-component initiatives, no programs were found to implement direct health and other sector nutrition interventions alone. However, a total of 11 country-level programs implemented indirect health sector nutrition interventions, entirely comprised of disease prevention and management for malaria, arbovirus, cholera, and diarrhea. Particular activities within these interventions included, but were not limited to, campaigns for routine long-lasting

insecticidal nets, indoor residual spraying, mass chlorination of water sources, and distribution of water purification tablets. The remaining single-component programs (n=31) implemented other sectoral strategies indirectly affecting nutrition, which comprised of the following interventions: poverty alleviation (n=30), water, sanitation, and hygiene (WASH) (n=10), household food security (n=2), education (n=1), and infrastructure (n=1). Poverty alleviation comprised the majority with anticipatory cash transfers and food vouchers ahead of climate-related hazards as common activities. WASH activities included the distribution of hygiene and dignity kits, provision of safe water, and the rehabilitation of water systems through reservoirs, boreholes and catchments. Similarly, infrastructural interventions included the construction of solar-powered boreholes and re-construction of damaged access points.

Notable single-component programs which showed positive benefits to nutrition were mostly due to proactive cash transfers ahead of forecasted climate-related hazards as a poverty alleviation (indirect other sector nutrition) intervention. These interventions were associated with three main programs titled Anticipatory Action (AA), Forecast-based Financing (FbF), or Early Warning, Early Action (EWEA), which are often used synonymously and all use climate information services to monitor and detect pre-agreed forecast thresholds set by respective governments and donors (i.e., United Nations Member States, international organizations, private sector, and philanthropists). Once thresholds are met, pre-pooled financing is distributed ahead of a forecasted climate-related hazard to vulnerable households with the intention of maintaining food security and building resilience to climate shocks. These proactive cash transfers have shown success in several impact evaluations conducted in Bangladesh, Madagascar, Malawi, Nepal, Somalia, and Zimbabwe. In virtually all cases, proactive cash transfers led to higher food consumption and food diversity, including more protein, vegetables, and lipid-based foods. Not only were these populations more likely to maintain food security, but they presented higher resilience capacity scores, less psychosocial stress, and overall better coping to climate-related hazards [35, 38, 44].

Moreover, two disease prevention and management interventions (indirect health sector nutrition interventions) were also shown to be beneficial in Chad and Malawi. Chad's bundled vector control plan was found to lower malaria transmission after implementing routine seasonal

malaria chemoprevention, long-lasting insecticide impregnated mosquito nets, and indoor residual spraying [20]. Likewise, Malawi found implementation of a mass water chlorination campaign ahead of a forecasted flood was most effective at preventing cholera incidence and curbing the burden among affected populations [56].

Multi-component programs

The following multi-component programs were found in the literature for direct health sector nutrition interventions: food supplementation (n=5), and micronutrient supplementation (n=1). This included ready-to-use supplementary foods and the distribution of vitamin A supplementation. For other sectoral strategies directly affecting nutrition, the following were included in these combinations: nutrition in emergency programmes (n=19), treatment and management of acute malnutrition (n=5), food fortification (n=1), in-school nutrition (n=1). These was primarily implemented in the form of food aid, which included ready-to-use therapeutic foods, fortified biscuits and school meals. Compared to the single-component programs, additional indirect health sector interventions were also found in the search: disease prevention and management (n=12); family planning and reproductive health, such as primary care initiatives for women of reproductive age and expecting mothers (n=4); and maternal mental health support, such as psychosocial counselling (n=3). Similar to the single-component programs, the following interventions were identified for indirect other sector nutrition intervention: poverty alleviation (n=19), WASH (n=14), education through various health and nutrition community campaigns (n=9), infrastructure (n=6), household food security (n=5), and women's empowerment through targeted initiatives to provide women more agency (n=1).

Notable multi-component programs which were beneficial in supporting nutrition were primarily found in Somalia. After the Famine Early Warning Systems Network (FEWS NET) had forecasted drought-related famine (IPC Phase 5 – Catastrophe) in 2022, humanitarian agencies implemented and coordinated a multi-component program with interventions from all sectors, including food aid, vitamin A supplementation, deworming tablets, mass vaccination for children for measles and cholera, WASH activities, and cash transfers. By 2023, FEWS NET had announced that famine was averted as a result of these measures, although acute food insecurity

across Somalia still remained high and varied between Crisis (IPC Phase 3) and Emergency (IPC Phase 4) depending on the region. Nonetheless, outreach was able to supply an average of over 6.2 million people per month with food and over 2 million children were vaccinated against measles, provided with vitamin A, and treated with deworming tablets [31, 57, 58].

Moreover, Somalia's AA plan was structured and deployed through their Baxnaano National Safety Net Program ahead of forecasted droughts between 2020 and 2023. This enabled affected populations to receive cash transfers through an existing and national-level social protection platform. In addition to integrated food assistance, prevention and treatment packages for acute malnutrition and in-school meals were coordinated by WFP and other local partners. While previous AA programs were developed for flood-prone countries, Somalia served as the first AA program which addressed impacts of drought and went beyond traditional financing to provide health care and nutrition sector-specific activities to further support food security among affected populations. After Somalia's drought AA activation in 2022, approximately USD 2.7 million in cash transfers were distributed to over 200,000 people while 25,000 children (<5 years old) and pregnant and breastfeeding women and girls received specialized nutritious foods to treat acute malnutrition. Additional impact evaluations also indicated that Somalia's AA recipients were less likely to resort to 'crisis' coping strategies, regardless of drought severity [44].

Discussion

This scoping review synthesized the use of climate information services to inform nutrition programming in LMICs, in advance of extreme weather and climate events. We find that most countries developed and used early warnings for floods and droughts, but to a lesser extent for extreme heat or cold wave events. As a result, the types of nutrition interventions deployed were largely outside of the direct health-care sector, including poverty alleviation, water, sanitation and hygiene activities, education or infrastructure. In addition, evaluations on the effectiveness of these interventions on nutrition outcomes in vulnerable groups was assessed up to one-year post-disaster. These evaluations indicated that early warnings had some success in ensuring healthy diets and reducing malnutrition, through the use of cash transfers. However, it is unclear, from this analysis, how the use of climate information services may improve nutrition in the

long-term, especially which interventions have the greatest benefit, their cost and potential barriers.

Importantly, the present study included large-scale climate information services that have been deployed in a number of countries by United Nations agencies such as WFP (AA and forecast-based financing), United Nations Children's Fund (Today and Tomorrow Initiative), as well as non-governmental organizations such as the International Federation of Red Cross and Red Crescent Societies (EWEA), Famine Early Warning Systems Network (International Food Security Phase Classification) and Start Network **(**Forecast-based Warning, Analysis, and Response Network). According to the State of Climate Services report, there have been significant efforts to develop and implement National Frameworks for Climate Services [65]. As of 2024, 98 countries have implemented a national framework, though significant gaps remain in recognizing the specific impacts of climate-related risks for children and women [65]. In comparison, the 2021 WHO health and climate change global survey reported progress governments have made in addressing the health risks of climate change, including the use of climate information services [66]. Their findings reveal that out of 70 countries with health surveillance systems, only 11% utilize climate information (short-term weather information, seasonal climate information or long-term climate information) for malnutrition and food-borne diseases and early warnings are in place for 12 countries (Azerbaijan, Bahrain, Cuba, Ethiopia, El Salvador, Germany, Israel, Madagascar, Marshall Islands, Netherlands, Palau and South Africa) [66].

In order to prioritize nutrition in the context of climate change, there are several actions that should be forefront in developing climate services, adaptation planning and decision-making. First, in understanding climate risks and vulnerabilities, as well as adaptation options, policymakers should adopt adaptation principles, such as those established by the Global Commission on Adaptation [67]. These principles ensure communities affected by climate change have a voice in the development of climate services and subsequent health system decisions by offering local, traditional, Indigenous, generational and scientific knowledge (Stage 1 of conceptual framework) [68]. Second, climate-informed nutrition programs should be integrated and multi-sectoral in their response to multiple hazards (Stage 2 of conceptual

framework). This means that, across the disaster management cycle and humanitarian, development and peace nexus, multiple sectors, ministries and agencies, including health, social welfare and infrastructure, must be engaged in developing strategies, coordination and implementation plans, as well as robust monitoring and evaluation systems to ensure learning. Third, climate information services can be incorporated into multiple health system building blocks for nutrition (Stage 3 of conceptual framework). For example, these services can inform human, financial and material resources needed ahead of extreme weather and climate events to prevent, or at least mitigate, acute and imminent humanitarian impacts. Health facilities and communities can stock essential nutrition supplements and treatments such as oral rehydration salts, micronutrient supplements and ready-to-use therapeutic foods, as well as ensure public health nutrition practitioners undertake climate training to be better equipped to act. In addition, climate information services, if designed well, can help to ensure good service delivery of effective, safe and quality nutrition interventions to targeted communities by incorporating spatial risk assessments and pre-arranged financing for nutrition actions that can be quickly dispersed once certain early warning thresholds are met. Finally, refining climate services relies on nutrition surveillance data collected within health facilities, communities (e.g., schools) or feeding centers (e.g., community-based management of acute malnutrition) [69] (Stage 4 of conceptual framework). These data can help inform the short- and long-term effectiveness of climate services on the burden of malnutrition after extreme weather and climate events. Together, these proactive measures can ensure a resilient and sustainable health system for nutrition.

Implications for Future Research, Policy and Practice

Based on the findings of the present study, there are several research, policy and practice recommendations for the broader scientific community, governments, as well as non-governmental organizations and civil society. First, to fill evidence gaps, there is urgency and opportunity for better integration of weather and climate information into health systems national decision-making and building preparedness capabilities at local levels to improve both short- and long-term nutrition outcomes. To make this possible, countries should adopt a standardized approach to enhance the development, delivery and use of climate information and services at a

national level. This means that we need a new architecture or a data ecosystem that facilitates continuous data sharing and surveillance, while bringing together multi-disciplinary expertise to better track climate hazards and nutrition vulnerabilities across sectors responsible for nutrition. This new architecture must go beyond utilizing a narrow set of climate indicators (i.e., precipitation and temperature) to monitor multiple extreme weather and climate events, such as floods and droughts, and consider filling evidence gaps related to extreme heat and cold. Second, in order for health systems to act on weather and climate information, there is a need for knowledge translation of climate information services to policymakers and practitioners, such that these services are understandable and interpretable, as well as integration of nutrition within climate adaptation commitments and plans (and vice versa) including sustainable financing mechanisms to ensure the adaptation and scale-up of nutrition interventions are appropriately resourced. Given this scenario, it is imperative for the nutrition community to support countries' efforts to step up and renew financial commitments and at the same time make the investment case for nutrition adaptation within the climate agenda to leverage climate funds. Finally, there is a need to gain global consensus on recommended packages of nutrition interventions (within and outside of the health sector) for specific climate hazards (Table 2).

546 **Table 2. Recommended nutrition intervention packages in preparation of extreme weather events**
547 Italic text indicates interventions not found in the included studies of this review, but are supported by external evidence [70-81]
548

Climate Event	Direct Health Sector	Indirect Health Sector	Other Sectoral Strategies
Flooding	Nutrition counselling including infant and young child feeding practices to mitigate undernutrition post-flood	Seasonal campaigns for vector- and water- borne disease prevention (handwashing, food and water storage, preparation) Distribution of health, hygiene, and dignity kits	Universal access to clean potable water and improved sanitation ensured, including wells/boreholes, water purification products, and mass chlorination Climate-resilient water and sanitation safety plans, including integrated water quality management and monitoring Provision of water, sanitation, and hygiene materials, including sanitation and hygiene kits
Drought	Nutrition counselling Food supplementation, including micronutrient, targeted and blanket supplementary feeding Treatment and management of moderate and severe acute malnutrition using ready- use-therapeutic- and supplementary-foods	Community mass outreach screening and referrals Deworming treatments Mass vaccination (measles and cholera)	Emergency food distribution/aid, including food fortification (e.g., iodized salt or fortified cereals) to address nutrient deficiencies Cash transfers, food vouchers, and cash-for-asset activities (forecast-based financing) Rehabilitation and reconstruction of water systems, including access to safe water via boreholes and catchments Community campaigns to improve safe water access and storage
Heatwaves	Oral rehydration salts to mitigate dehydration		Access to cooling and hydration centres, including delivery of potable water to households (i.e., self-dousing, consuming, ice towels, water sprays, cooling/misting fans) for electrolyte supplementation

			Infrastructural changes, such as increasing green space, community shading zones, and prioritizing heat-resistant materials *Educational interventions to improve knowledge and awareness of heat stress prevention strategies*
Cold waves	*Nutrition counselling including infant and young child feeding practices to mitigate undernutrition* *Food supplementation, including micronutrient, targeted and blanket supplementary feeding* *Treatment and management of moderate and severe acute malnutrition using ready- use-therapeutic- and supplementary-foods*	Mental health and psychosocial support and counselling	Emergency food distribution/aid, including food fortification (e.g., iodized salt or fortified cereals) to address nutrient deficiencies Cash transfers, food vouchers, and cash-for-asset activities (forecast-based financing) Provision of basic supplies (e.g., warm clothing and accessories, first aid kits) to prevent hypothermia Destocking-for cash (particularly for pastoral and rural communities) Infrastructural adaptations, including adequate insulation, weather stripping and improving heating systems Increasing educational resources, including Social and Behavior Change campaigns to build climate awareness Snow-clearing and emergency service vehicles to transport vulnerable populations to health facilities
Storms	Nutrition counselling including infant and young child feeding practices to mitigate undernutrition	Accessible medical services, including continued family planning, reproductive health, and neonatal care (e.g., medication, clean delivery kits)	Community campaigns to improve safe water access and storage Provision of water, sanitation, and hygiene materials, including water filters, handwashing devices, WASH kits, and water purification products

		Mental health and psychosocial support and counselling	Infrastructural restorations, rehabilitation and adaptations, including cleaning/disinfecting wells, roof reinforcements, and installing temporary facilities Increasing educational resources, including social and behavior change campaigns to build awareness and providing supplies (e.g., tents, tarps, school and recreation kits, early childhood development kits, learning materials, blackboards and school tables)

Strengths and Limitations

Despite the breadth and depth of literature examined, our review highlights a critical gap in the literature examining the use of climate information services and resulting impacts on nutrition. Although there is recognition amongst nutrition practitioners that climate change and variability will inevitably influence patterns of undernutrition and micronutrient deficiencies, effective coordination mechanisms between climate and nutrition spheres are conspicuously absent. Consequently, climate considerations remain largely peripheral to established nutrition frameworks, neither adequately incorporated into programming and policies nor subjected to systematic evaluation – a disconnect that undermines holistic approaches to addressing these intertwined challenges.

Conclusion

In summary, this synthesis identified a variety of country-level programs that bridge humanitarian, development and peace mandates in the context of climate change by aligning disaster risk reduction, preparedness, and anticipatory action, with emergency response, recovery, and sustainable reconstruction through build back better approaches. However, many of these programs delivered nutrition interventions that were indirect or outside the health sector, in preparation of floods and droughts. To integrate climate services and information activities for nutrition, cooperation and partnership between providers and users of climate information is required to ensure climate services are designed in response to the specific needs. These efforts can promote active knowledge sharing and the harnessing of data and scientific advances to better meet the climate information needs for public health nutrition preparedness.

Conflicts of Interest: None to declare.

Funding Sources: This review was supported by a generous gift from the Eleanor Crook Foundation to Columbia Climate School.

Data Availability Statement: The search terms used in this scoping review are available in the Supporting Information file, and extracted data are publicly available from included studies.

Author Contributions: BC and JF conceptualized the study. BC and GD developed the protocol and ran searches. BC and GD screened and reviewed studies. GD extracted studies. BC and GD wrote the first draft and all authors revised and approved the final manuscript.

References

1. Food and Agriculture Organization. Climate action and nutrition – Pathways to impact. Rome: 2023.
2. Seneviratne SI, Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, Iskandar, S.I., Kossin, J., Lewis, S.,, Otto F, Pinto, I., Satoh, M., Vicente-Serrano, S.M., Wehner, M and Zhou B. Weather and Climate Extreme Events in a Changing Climate. In: Intergovernmental Panel on Climate C, editor. Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2023. p. 1513-766.
3. Zhu Y, He C, Gasparrini A, Vicedo-Cabrera AM, Liu C, Bachwenkizi J, et al. Global warming may significantly increase childhood anemia burden in sub-Saharan Africa. One Earth. 2023;6(10):1388-99. doi: 10.1016/j.oneear.2023.09.003. PubMed PMID: 37904727; PubMed Central PMCID: PMCPMC7615260.
4. Rosegrant MW, Sulser TB, Dunston S, Mishra A, Cenacchi N, Gebretsadik Y, et al. Food and nutrition security under changing climate and socioeconomic conditions. Global Food Security. 2024;41. doi: 10.1016/j.gfs.2024.100755.
5. Street RB. Towards a leading role on climate services in Europe: A research and innovation roadmap. Climate Services. 2016;1:2-5. doi: https://doi.org/10.1016/j.cliser.2015.12.001.
6. Warner D, Moonsammy S, Joseph J. Factors that influence the use of climate information services for agriculture: A systematic review. Climate Services. 2022;28. doi: 10.1016/j.cliser.2022.100336.
7. Born L, Prager S, Ramirez-Villegas J, Imbach P. A global meta-analysis of climate services and decision-making in agriculture. Climate Services. 2021;22:100231. doi: https://doi.org/10.1016/j.cliser.2021.100231.
8. Connor SJ, Mantilla GC. Integration of Seasonal Forecasts into Early Warning Systems for Climate-Sensitive Diseases such as Malaria and Dengue. In: Thomson MC, Garcia-Herrera R, Beniston M, editors. Seasonal Forecasts, Climate Change and Human Health: Health and Climate. 30. New York: Springer International Publishing; 2008. p. 71-84.
9. Thomson MC, Mason SJ. Climate information for public health action. London ; New York: Routledge, Taylor & Francis Group; 2019. xxviii, 243 pages p.
10. Mariotti A, Ruti PM, Rixen M. Progress in subseasonal to seasonal prediction through a joint weather and climate community effort. npj Climate and Atmospheric Science. 2018;1(1). doi: 10.1038/s41612-018-0014-z.
11. Pechlivanidis I, Crochemore L. Seamless blending of subseasonal and seasonal forecasts. Climate Services for Clean Energy (S2S4E); 2020.
12. Reinhardt K, Fanzo J. Addressing Chronic Malnutrition through Multi-Sectoral, Sustainable Approaches: A Review of the Causes and Consequences. Front Nutr. 2014;1:13. Epub 20140815. doi: 10.3389/fnut.2014.00013. PubMed PMID: 25988116; PubMed Central PMCID: PMCPMC4428483.
13. Keats EC, Das JK, Salam RA, Lassi ZS, Imdad A, Black RE, et al. Effective interventions to address maternal and child malnutrition: an update of the evidence. Lancet Child Adolesc Health. 2021;5(5):367-84. Epub 20210307. doi: 10.1016/S2352-4642(20)30274-1. PubMed PMID: 33691083.

14. World Health Organization. Operational framework for building climate resilient and low carbon health systems. 2023.
15. World Bank. World Bank Country and Lending Groups 2024. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
16. World Health Organization. Countries 2025. Available from: https://www.who.int/countries.
17. Keats EC, Das JK, Salam RA, Lassi ZS, Imdad A, Black RE, et al. Effective interventions to address maternal and child malnutrition: an update of the evidence. The Lancet Child & Adolescent Health. 2021;5(5):367-84. doi: 10.1016/s2352-4642(20)30274-1.
18. Bazo J, de Perez C, Jacome G, Mantilla K, Destrooper M, Van Aalst M. Anticipation Mechanism for Cold Wave: Forecast Based Financing a Case Study in the Peruvian Andes. Front Clim. 2021;3. doi: 10.3389/fclim.2021.747906.
19. Beek K, Drysdale R, Kusen M, Dawson A. Preparing for and responding to sexual and reproductive health in disaster settings: evidence from Fiji and Tonga. Reprod Health. 2021;18(1). doi: 10.1186/s12978-021-01236-2.
20. Djaskano MI, Cissoko M, Diar MSI, Israel DK, Clément KH, Ali AM, et al. Stratification and Adaptation of Malaria Control Interventions in Chad. Trop Med Infect Dis. 2023;8(9). doi: 10.3390/tropicalmed8090450.
21. Funk C, Shukla S, Thiaw WM, Rowland J, Hoell A, McNally A, et al. Recognizing the Famine Early Warning Systems Network: Over 30 Years of Drought Early Warning Science Advances and Partnerships Promoting Global Food Security. Bulletin of the American Meteorological Society. 2019;100(6):1011-27. doi: 10.1175/BAMS-D-17-0233.1. PubMed PMID: WOS:000472767600006.
22. Mukabutera A, Thomson DR, Hedt-Gauthier BL, Atwood S, Basinga P, Nyirazinyoye L, et al. Exogenous factors matter when interpreting the results of an impact evaluation: a case study of rainfall and child health programme intervention in Rwanda. Trop Med Int Health. 2017;22(12):1505-13. doi: 10.1111/tmi.12995.
23. Okullo AE, Matovu JKB, Ario AR, Opigo J, Wanzira H, Oguttu DW, et al. Malaria incidence among children less than 5 years during and after cessation of indoor residual spraying in Northern Uganda. Malar J. 2017;16(1). doi: 10.1186/s12936-017-1966-x.
24. Smith LC, Frankenberger TR. Does Resilience Capacity Reduce the Negative Impact of Shocks on Household Food Security? Evidence from the 2014 Floods in Northern Bangladesh. World Development. 2018;102:358-76. doi: 10.1016/j.worlddev.2017.07.003. PubMed PMID: WOS:000417657500024.
25. Stewart-Ibarra AM, Romero M, Hinds AQJ, Lowe R, Mahon R, van Meerbeeck CJ, et al. Co-developing climate services for public health: Stakeholder needs and perceptions for the prevention and control of Aedestransmitted diseases in the Caribbean. PLoS Negl Trop Dis. 2019;13(10). doi: 10.1371/journal.pntd.0007772.
26. Thomson MC, Ukawuba I, Hershey CL, Bennett A, Ceccato P, Lyon B, et al. Using rainfall and temperature data in the evaluation of national malaria control programs in Africa. Am J Trop Med Hyg. 2017;97:32-45. doi: 10.4269/ajtmh.16-0696.
27. Avdeenko A, Frölich M. Impacts of increasing community resilience through humanitarian aid in Pakistan. 2019.
28. Bank AD. Atlas of Landslides in the Kyrgyz Republic. 2023.

29. Dolan C, Shoham J. Humanitarian-Development Nexus: Nutrition programming and policy in Kenya. Emergency Nutrition Network, 2017.
30. Government of Lesotho. Lesotho Post-Disaster Needs Assessment : Heavy Rains 2010-11. 2011.
31. Integrated Food Security Phase Classification (IPC). Large scale, multi-sectoral assistance will likely avert Famine (IPC Phase 5), but 6.5 million people in Somalia still face Crisis (IPC Phase 3) or worse acute food insecurity outcomes. 2023.
32. Shafee M, Zapata L. Leveraging climate risk data tools to inform social protection: The case of WFP's Platform for Real-time Impact and Situation Monitoring (PRISM). World Food Programme, 2023.
33. United Nations Office for Disaster Risk Reduction, World Meteorological Organization. Global Status of Multi-Hazard Early Warning Systems 2023. 2023.
34. World Food Programme. Cash transfers and vouchers in response to drought in Mozambique: Lessons on social protection linkages and separation of functions. 2019.
35. World Food Programme. Acting Before a Flood to Protect the Most Vulnerable: An Independent Review of WFP's Anticipatory Cash Transfers in Bangladesh. 2021.
36. World Food Programme. A System to Anticipate and Address the Impacts of Drought in Zimbabwe: An overview of partnerships, capacity strengthening and activations. 2022.
37. World Food Programme. Anticipatory Cash Transfers and Early Warning Information Ahead of Drought in Ethiopia. 2022.
38. World Food Programme. Scaling up anticipatory actions for food security: anticipatory action year in focus 2022. 2022.
39. World Food Programme. Anticipatory Action to support communities ahead of floods through social protection system in Haiti. 2023.
40. World Food Programme. WFP Somalia: Anticipatory action and integrated climate risk management. 2023.
41. World Food Programme. Anticipatory Action against El Niño: WFP's regional response in Southern Africa. 2023.
42. World Food Programme. WFP activates Anticipatory Action to support communities ahead of the impacts of drought in the Dry Corridor, Guatemala. 2023.
43. World Food Programme. Anticipatory actions to mitigate flash flood impact in Bangladesh. 2023.
44. World Food Programme. Scaling up anticipatory actions for food security: anticipatory action year in focus 2023. 2023.
45. World Food Programme. Joint Post-Distribution Monitoring (PDM) of Forecast-based Anticipatory Action Project (FbAA) – 2022. 2023.
46. World Food Programme. Climate and Resilience Actions in Eastern Africa. 2023.
47. World Food Programme. Supercharging social protection systems with anticipatory cash: Case study on Fiji's Anticipatory Action Framework. 2024.
48. World Food Programme. Anticipatory action to mitigate the impacts of monsoon floods in Northern Bangladesh. 2024.
49. World Health Organization. Strengthen control of vectorborne diseases to lessen the impact of climate change in the Western Pacific Region with focus on Cambodia, Mongolia and Papua New Guinea. 2012.
50. Ewbank R, Perez C, Cornish H, Worku M, Woldetsadik S. Building resilience to El Nino-related drought: experiences in early warning and early action from Nicaragua and

722 Ethiopia. Disasters. 2019;43 Suppl 3(Suppl 3):S345-S67. doi: 10.1111/disa.12340. PubMed
723 PMID: 30945769; PubMed Central PMCID: PMCPMC6850149.
724 51. Food and Agriculture Organization of the United Nations. Impact of Early Warning Early
725 Action Madagascar. Protecting farming livelihoods from drought and food insecurity. Rome:
726 2019.
727 52. Gros C, Bailey M, Schwager S, Hassan A, Zingg R, Uddin MM, et al. Household-level
728 effects of providing forecast-based cash in anticipation of extreme weather events: Quasi-
729 experimental evidence from humanitarian interventions in the 2017 floods in Bangladesh.
730 International Journal of Disaster Risk Reduction. 2019;41. doi: 10.1016/j.ijdrr.2019.101275.
731 53. International Federation of Red Cross and Red Crescent Societies (IFRC). Forecast-based
732 financing for vulnerable herders in Mongolia. 2017.
733 54. Jjemba EW, Mwebaze BK, Arrighi J, de Perez EC, Bailey M. Forecast-Based Financing
734 and Climate Change Adaptation: Uganda makes history using science to act early before a flood.
735 In: Zommers Z, Alverson K, editors. Resilience: The science of adaptation to climate change:
736 Elsevier; 2018. p. 237-42.
737 55. Pople A, Hill R, Dercon S, Brunckhorst B. Anticipatory cash transfers in climate disaster
738 response. Centre for Disaster Protection, 2021.
739 56. Start Network. Case study: Start Fund Alert 220 Malawi anticipation of cholera outbreak
740 London2018. Available from: https://startnetwork.org/learn-change/news-and-blogs/mitigating-
741 deadly-cholera-outbreak-malawi.
742 57. Famine Early Warning Systems Network. Somalia Food Security Outlook: Famine (IPC
743 Phase 5) would likely occur if food assistance plans do not materialize. 2022.
744 58. Famine Early Warning Systems Network. Somalia Food Security Outlook: Gradual
745 drought recovery continues, though millions still need assistance. 2024.
746 59. World Food Programme. Mozambique: Anticipating Extreme Weather. 2022.
747 60. World Food Programme. Anticipatory Action to mitigate the impact of El Niño-induced
748 floods in Burundi. 2023.
749 61. World Food Programme. Anticipatory actions to mitigate El Nino's flood impact in
750 Somalia. 2023.
751 62. World Food Programme. Anticipatory Action in Ethiopia: Drought Activation For
752 Somali Region. 2024.
753 63. World Food Programme. Anticipatory Action 2022 activation in Somali Region,
754 Ethiopia. 2024.
755 64. World Health Organization. Climate change and health in the Western Pacific Region:
756 synthesis of evidence, profiles of selected countries and policy direction. 2015.
757 65. World Meterology Organization. State of Climate Services. 2024.
758 66. World Health Organization. 2021 WHO Health and Climate Change Survey Report.
759 Geneva: 2021.
760 67. Global Commission on Adaptation. Principles for Locally Led Adaptation Action 2021.
761 Available from: https://gca.org/wp-
762 content/uploads/2022/04/Locally_Led_Adaptation_Principles_-_Endorsement_Version.pdf.
763 68. Mailloux NA, Henegan CP, Lsoto D, Patterson KP, West PC, Foley JA, et al. Climate
764 Solutions Double as Health Interventions. Int J Environ Res Public Health. 2021;18(24). Epub
765 20211218. doi: 10.3390/ijerph182413339. PubMed PMID: 34948948; PubMed Central PMCID:
766 PMCPMC8705042.

69. Tuffrey V, Hall A. Methods of nutrition surveillance in low-income countries. Emerg Themes Epidemiol. 2016;13:4. Epub 20160318. doi: 10.1186/s12982-016-0045-z. PubMed PMID: 26997966; PubMed Central PMCID: PMCPMC4797352.
70. Agabiirwe CN, Dambach P, Methula TC, Phalkey RK. Impact of floods on undernutrition among children under five years of age in low- and middle-income countries: a systematic review. Environ Health. 2022;21(1):98. Epub 20221024. doi: 10.1186/s12940-022-00910-7. PubMed PMID: 36274126; PubMed Central PMCID: PMCPMC9590165.
71. Bhandari D, Bi P, Craig JM, Robinson E, Pollock W, Lokmic-Tomkins Z. Mobilising and evaluating existing heat adaptation measures to protect maternal and child health. Lancet Planet Health. 2024;8(7):e424-e5. doi: 10.1016/S2542-5196(24)00113-X. PubMed PMID: 38969467.
72. Conlon KC, Rajkovich NB, White-Newsome JL, Larsen L, O'Neill MS. Preventing cold-related morbidity and mortality in a changing climate. Maturitas. 2011;69(3):197-202. Epub 20110517. doi: 10.1016/j.maturitas.2011.04.004. PubMed PMID: 21592693; PubMed Central PMCID: PMCPMC3119517.
73. Hasan F, Marsia S, Patel K, Agrawal P, Razzak JA. Effective Community-Based Interventions for the Prevention and Management of Heat-Related Illnesses: A Scoping Review. Int J Environ Res Public Health. 2021;18(16). Epub 20210807. doi: 10.3390/ijerph18168362. PubMed PMID: 34444112; PubMed Central PMCID: PMCPMC8394078.
74. International Federation of Red Cross and Red Crescent Societies. Peru: Extreme cold and snowfall - Early Action Protocol summary. 2019.
75. Li H, Bardhan R, Debnath R. Heatwave interventions must reduce invisible gendered challenges in the Global South. PLOS Glob Public Health. 2024;4(10):e0003625. Epub 20241024. doi: 10.1371/journal.pgph.0003625. PubMed PMID: 39446713; PubMed Central PMCID: PMCPMC11500927.
76. Pan American Health Organization. Heatwaves: A Guide for Health-based Actions. Washington, D.C.: 2021.
77. United Nations Children Fund. Innovative finance reshaping cyclone resilience and child-responsive disaster management in Madagascar. 2024.
78. United Nations Children Fund. Innovative financing for a safer future: reshaping cyclone resilience and child-responsive disaster management - Year 1 Results of the Today and Tomorrow Initiative. 2024.
79. United Nations Office for Disaster Risk Reduction. Heatwaves: Addressing a sweltering risk in Asia-Pacific. 2022.
80. United Nations Office for the Coordination of Humanitarian Affairs, United Nations Country Team Mongolia. 2024 Dzud Early Action & Response Plan Mongolia. 2024.
81. World Health Organization. Technical series on adapting to climate sensitive health impacts: diarrhoeal diseases. Geneva: WHO, 2022.

806

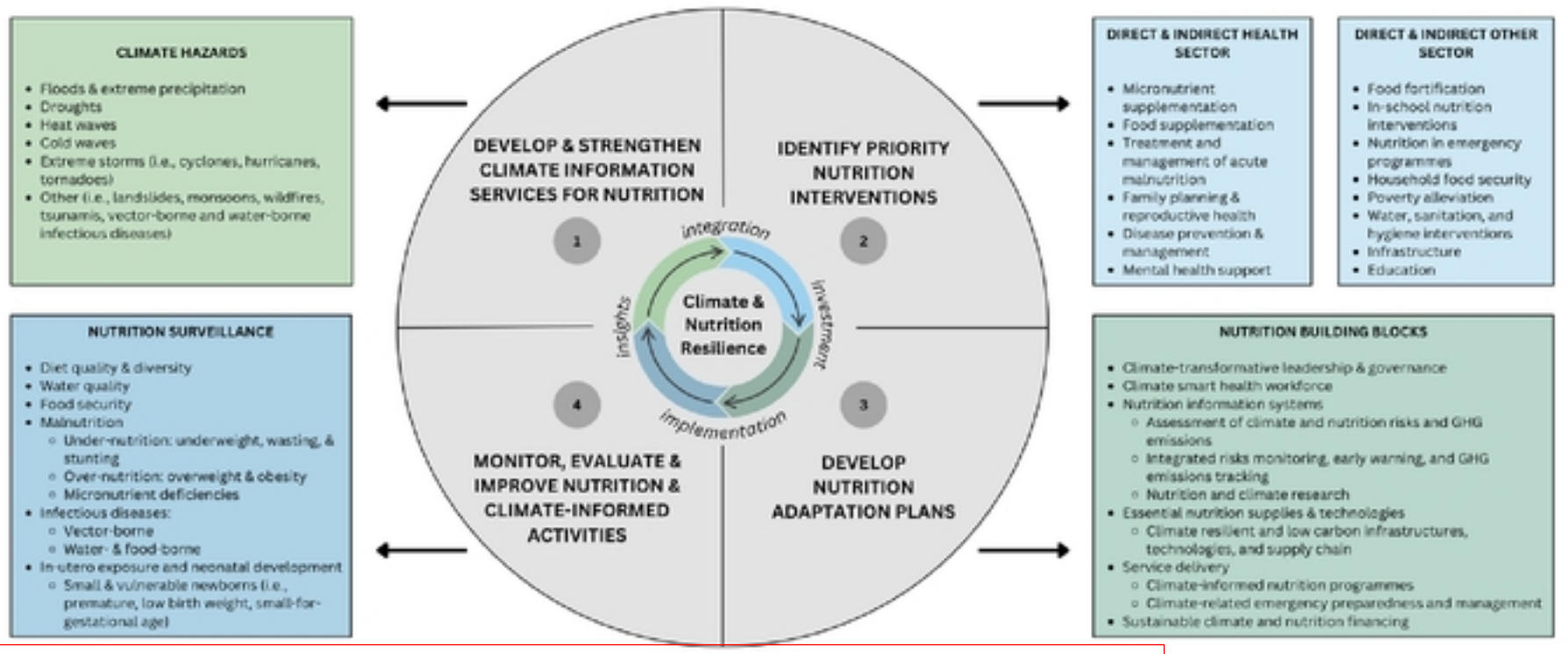

Figure 1. Climate Information and National Nutrition Planning and Response Conceptual Framework

Figure 1

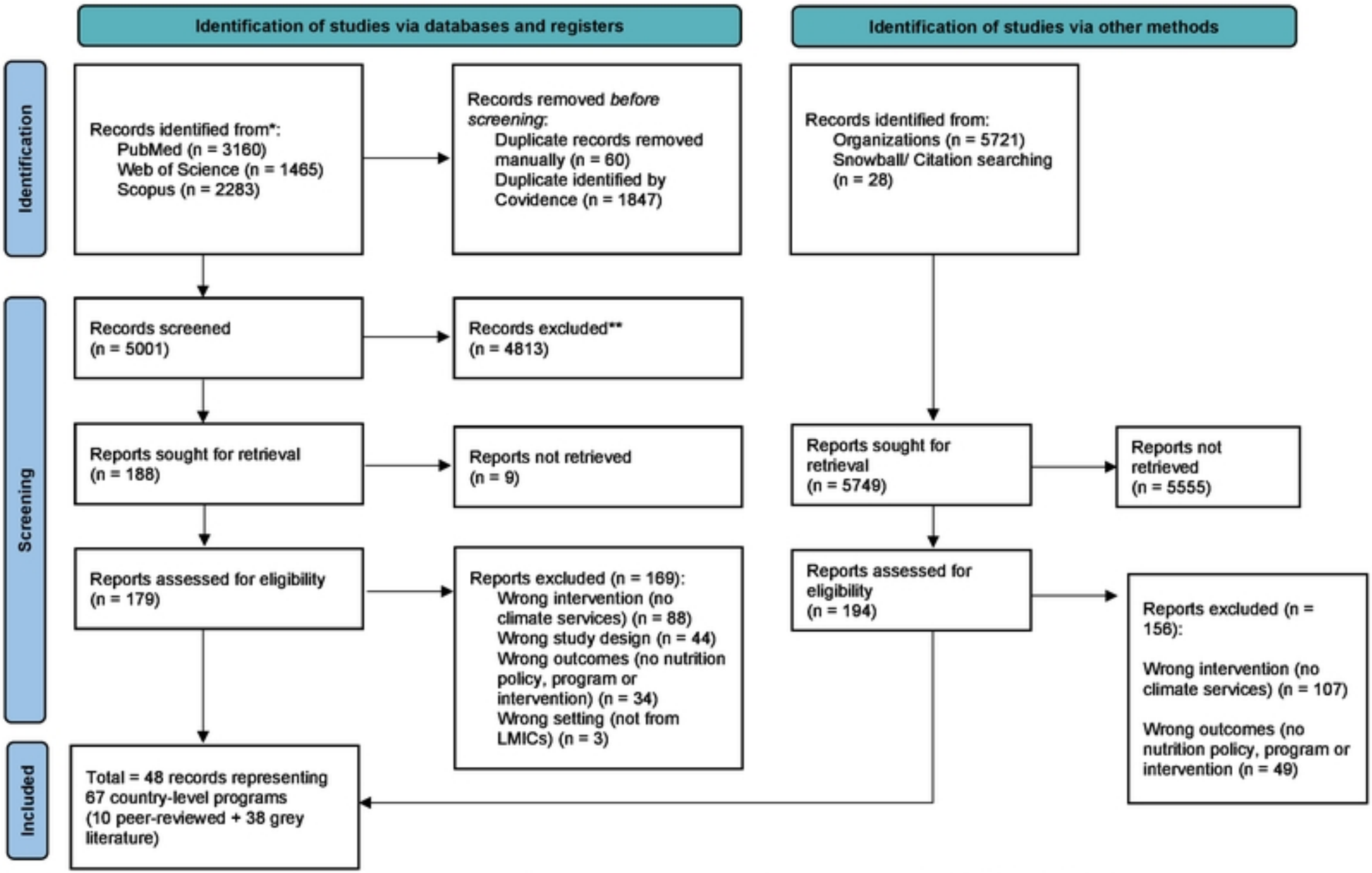

Figure 2. Preferred reporting items for systematic reviews and meta-analyses for scoping reviews (PRISMA-ScR)

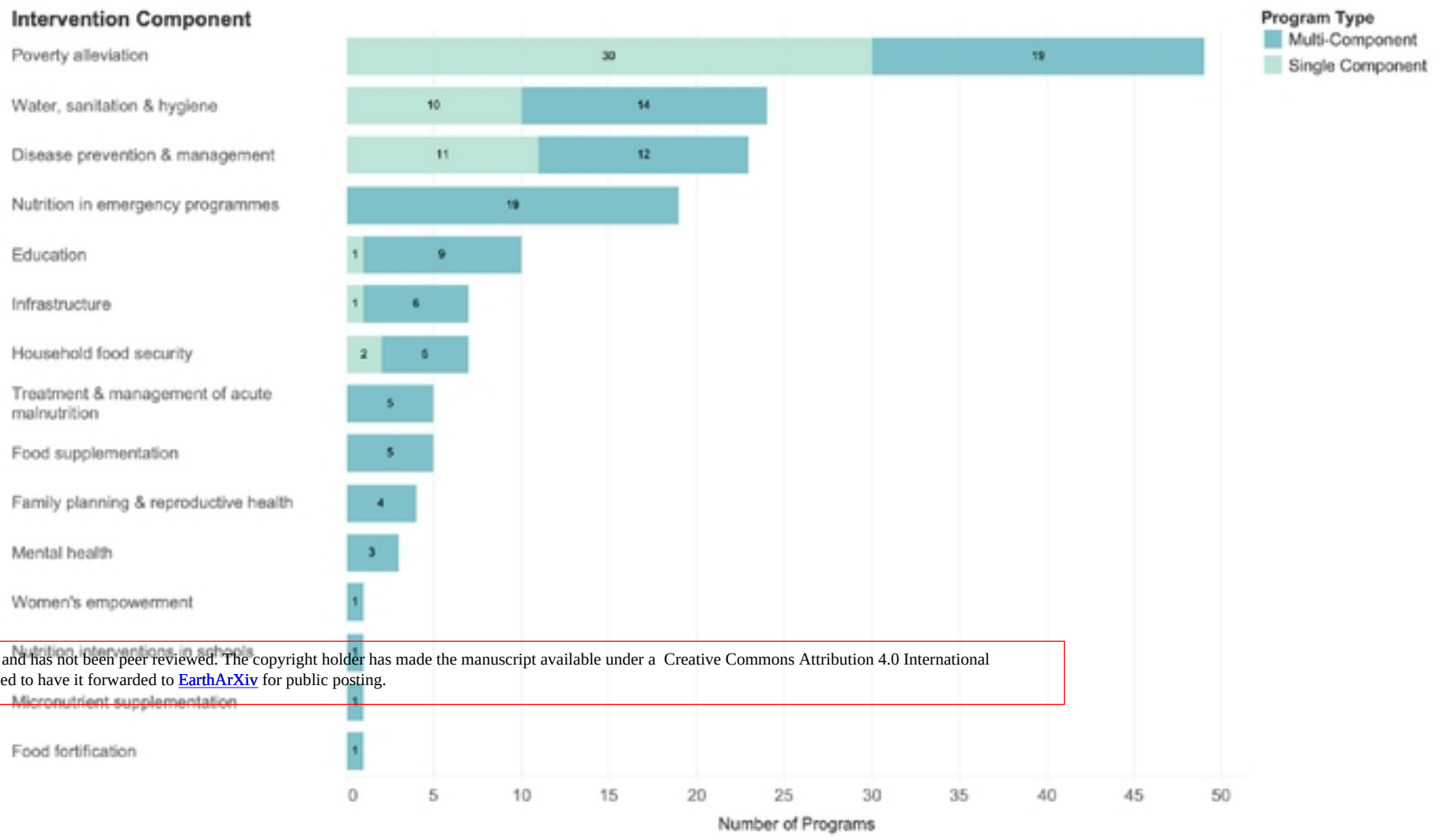

Figure 3. Number of Programs, by Intervention Type and Component

Figure 3