Understanding the persistence of malnutrition in the Sahel - Drivers of persistent high rates of undernutrition in the Sahel

Consolidated final report

February 2026

NUTRITION RESEARCH FACILITY
Knowledge and Research for Nutrition

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List of Acronyms

Acronym	Description
BF	Burkina Faso
BMI	Body Mass Index
CAM	Cameroon
CHA	Chad
CILSS	Permanent Interstate Committee for Drought Control in the Sahel
CINAHL	Cumulative Index to Nursing and Allied Health Literature
COVID-19	Coronavirus Disease 2019
DHS	Demographic and Health Surveys
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
HINARI	Health InterNetwork Access to Research Initiative
IBSS	International Bibliography of the Social Sciences
IFPRI	International Food Policy Research Institute
INTPA/F3	European Commission Directorate-General for International Partnerships, Unit F3 (Sustainable Agri-food Systems and Fisheries)
IPC	Integrated Food Security Phase Classification
LMICs	Low- and Middle-Income Countries
MAL	Mali
MAU	Mauritania
MDD	Minimum Dietary Diversity
MDD-W	Minimum Dietary Diversity for Women
MUAC	Mid-Upper Arm Circumference
NGA	Nigeria
NIG	Niger
NRF	Nutrition Research Facility
RAE	Relative Absolute Error
SD	Standard Deviation
SEN	Senegal
SMART	Standardised Monitoring and Assessment of Relief and Transitions
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
WASH	Water, Sanitation and Hygiene
WFP	World Food Programme
WHO	World Health Organisation
WRA	Women of Reproductive Age

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Contributors

This report was written by Gabriela Albuquerque and Luís Goulão (Instituto Superior de Agronomia (ISA), University of Lisbon), who led the overall design and coordination of the study and were responsible for the systematic review component. Additional contributions were made by Carl Lachat and Paolo Sarfatti (Ghent University), who are also members of the NRF research team.

Acknowledgements

The authors acknowledge the contributions of all researchers involved in the study, as well as those of national institutions, technical and financial partners, civil society organisations and community representatives who participated in interviews, focus group discussions and stakeholder workshops. Their engagement and insights were essential to contextualising the findings and grounding the analysis in local realities.

The machine-learning analysis was conducted by a research team from the Institute of Geography and Spatial Planning (IGOT), University of Lisbon, led by Paulo Morgado, with Sandra Oliveira (co-lead), Ana Rita Morais, César Capinha and Hugo Velhinho as researchers, and João Serras as consultant.

The qualitative case study was implemented by a research team from the Nouna Health Research Centre, Burkina Faso, led by Hervé Hien, with Alain Hien, Ali Sie, Bernadette T. Picbougoum, Kagoné Moubassira and Mamadou Ouattara. The study was conducted in close collaboration with partners in Niger, notably Ahmed M. Arzika (Centre de Recherche et Interventions en Santé Publique, Niger). The authors also thank Souheila Abbeddou (Ghent University) for her methodological support and backstopping to the NRF research team, as well as for her close collaboration with the Nouna Health Research Centre.

Executive summary

Undernutrition remains a persistent and critical public health challenge across the Sahel, despite decades of sustained investment in nutrition-specific and nutrition-sensitive interventions. High levels of stunting, wasting and anaemia among children under five and women of reproductive age continue to characterise the region, frequently reaching or exceeding emergency thresholds. This apparent paradox—continued high undernutrition prevalence in the presence of extensive programming—has been raised by decision-makers during an NRF consultation in West Africa as a central concern for nutrition policy in the Sahel.

The study recognises that nutrition outcomes in the Sahel are influenced not only by the availability of interventions, but by the conditions under which they are implemented. Immediate causes of undernutrition operate within persistent underlying and systemic constraints, including poverty, gender inequality, environmental stress, insecurity and institutional fragility, which can undermine programme effectiveness. Against this background, the study aimed to identify the drivers influencing undernutrition outcomes in the Sahel and to examine how these drivers interact across immediate, underlying and systemic levels.

To address this objective, the study adopted a mixed-methods design combining three complementary components. First, a systematic review synthesised published scientific and grey literature on the drivers of undernutrition in Sahelian contexts, using a best-fit framework synthesis approach anchored in the UNICEF/Young conceptual framework for acute malnutrition in Africa's drylands. Second, a machine-learning analysis was applied to harmonised, geocoded survey, environmental and contextual datasets across Sahelian countries sharing comparable ecological characteristics, enabling exploration of non-linear relationships and interactions among many potential drivers. Third, a qualitative case study, including a desk review, stakeholder roundtables, interviews and focus group discussions, was conducted in Burkina Faso and Niger to capture contextual perspectives, often poorly reflected in quantitative data. Together, these components enabled triangulation across evidence types and scales, providing a more comprehensive understanding of the persistence of undernutrition in the Sahel. The study focus countries are Burkina Faso, Chad, Mali, Mauritania, Niger and Senegal.

What emerged from the existing published evidence

The systematic review included 46 publications and identified a total of 51 drivers of undernutrition in the Sahel reported in the literature. Notably, systemic drivers were most often reported (71.7% of publications), followed by immediate (60.9%), and underlying (52.2%) drivers. The distribution of reported drivers reflected what is mostly routinely measured through population surveys rather than the full range of factors influencing nutrition outcomes.

Immediate drivers most cited included inadequate dietary intake, infectious diseases and poor maternal nutritional status. Underlying drivers frequently related to household food insecurity, inadequate infant and young child feeding practices, and insufficient access to health services, Water, Sanitation and Hygiene (WASH), and social protection. Systemic drivers were particularly prominent, notably poverty and low economic stability, low levels of education, gender inequality, weak governance, political instability, conflict and displacement, fragile food and health systems, and climate-related stressors such as droughts, floods and strong seasonality.

Most publications were focused on child stunting, *vis-a-vis* drivers of wasting and anaemia (particularly among women of reproductive age). Evidence was also uneven across countries: Burkina Faso, Mali and Senegal were relatively well documented, whereas Chad and Mauritania were considerably less represented.

Additional data insights

The machine-learning analysis complemented these findings by identifying a limited set of cross-cutting drivers that consistently explained variation in stunting, wasting and underweight across the study area.

Indicators related to women's human capital and agency, such as literacy, decision-making autonomy, contraceptive use and access to reproductive health services, emerged as particularly influential across outcomes. Environmental and climatic constraints, notably seasonal water supply variability and land characteristics, also ranked among the strongest undernutrition predictors. Socioeconomic conditions and household infrastructure further shaped outcomes, while gaps in child preventive care contributed to vulnerability. Of the three outcomes studied, stunting, underweight and wasting, the latter was associated with a broader and more fragmented set of variables needed to explain its variation, reflecting a higher sensitivity to short-term shocks, instability and compounded risks.

Although machine-learning models do not establish causality, these findings highlighted the importance of interacting constraints across causal levels and reinforced that undernutrition in the Sahel cannot be explained by isolated nutrition-specific factors alone. The recurrence of similar drivers across outcomes supports the case for integrated, multisectoral intervention packages rather than fragmented actions.

How vulnerabilities are experienced on the ground

The qualitative case study provided critical insight into how these drivers are experienced at household, community and service-delivery levels. Stakeholders and community members consistently identified systemic vulnerabilities, including chronic poverty, insecurity, climate variability, weak governance, demographic dynamics and restrictive gender norms, as key influences in both household conditions and service delivery environments. These systemic constraints translated into underlying determinants such as limited access to health services, Water, Sanitation and Hygiene (WASH) deficits, reproductive health pressures and fragile care environments. In turn, these underlying conditions influenced immediate factors, including poor dietary diversity, high disease burden and suboptimal feeding practices.

Examples were described of how sociocultural norms shape behaviours often labelled as "inappropriate" or "non-compliant", in programme discourse. Practices such as food sharing, sale of nutrient-rich foods, redistribution of therapeutic products or delayed care-seeking were frequently rational responses to scarcity, social obligations and service instability, rather than indicators of low knowledge or motivation. Divergent interpretations among actors (between policy-level, field-level and community perspectives) were shown to hinder coherent action and shared accountability, reinforcing fragmentation in programme design and implementation.

Why undernutrition persists, and what does this mean for programming

A consistent picture emerged across this study: persistent undernutrition in the Sahel is the product of interacting constraints across immediate, underlying and systemic causes, rather than gaps in technical knowledge or intervention coverage alone. The challenges in addressing these cross-level dynamics help explain why nutrition gains remain fragile in contexts facing recurrent shocks, institutional instability and environmental stress.

The study suggests that programme formulation should explicitly account for these interconnected constraints. This implies prioritising integrated, multisectoral intervention packages grounded in local implementation realities and designed to address cross-level drivers and anticipate caregiving and service-level trade-offs. In practice, this includes:

- Addressing poverty as a central cross-cutting constraint that simultaneously limits dietary quality, caregiving capacity, access to services, women's autonomy and resilience to shocks.
- Placing women's empowerment and reproductive health at the centre of nutrition strategies, recognising their consistent influence on caregiving practices, fertility-related pressures and health-seeking behaviours.

- Aligning nutrition actions with climate adaptation, water management and seasonality-sensitive interventions, acknowledging the role of environmental variability and predictable seasonal stress in shaping vulnerability.
- Designing delivery models that reflect service-level constraints and caregiving trade-offs in fragile and crisis-affected settings, including insecurity, staff shortages and service interruptions.

Strengthening the science–policy interface can support this shift, namely through a more systematically integration of quantitative, qualitative and participatory evidence through structured triangulation. This was revealed essential, in this study, to interpret complex cross-level interactions and to inform context-sensitive programming in fragile and shock-prone environments such as the Sahel. Furthermore, monitoring and evaluation systems should expand beyond short-term nutrition indicators and outputs, to capture service quality, care environments, gender dynamics and environmental stressors, thereby improving learning and accountability.

Keywords

Anaemia; drivers of undernutrition; evidence-informed decision-making; malnutrition; participatory research; Sahel; stunting; wasting.

Background and objective

Undernutrition is a major public health challenge in the Sahel, with persistently high prevalence of stunting, wasting, and anaemia among children under five and women of reproductive age. However, despite decades of investment by national governments and international partners (including the European Union (EU)) in nutrition interventions (nutrition programming and humanitarian assistance) in the region, undernutrition prevalence remains high. These investments include Integrated Management of Acute Malnutrition and health systems strengthening, promotion of infant and young child feeding and maternal-adolescent nutrition, micronutrient supplementation and fortification, WASH, social protection and nutrition-sensitive agriculture diversification initiatives[1].

This paradox led decision-makers during the NRF consultation on West Africa to raise a central question: *Why do high levels of undernutrition continue in the Sahel despite regular programmes and significant investment?* To address this question, the Nutrition Research Facility assumed the following theory of change: programme effectiveness depends on the availability of interventions but also on the contextual drivers that shape their outcomes. If these drivers are identified and linked to systemic, underlying, and immediate causes; if actions and investments are designed with this understanding; and if their undermining effects on implementation are reduced; then nutrition programmes will be more effective and contribute to reducing the prevalence and incidence of undernutrition in the Sahel (Figure 1).

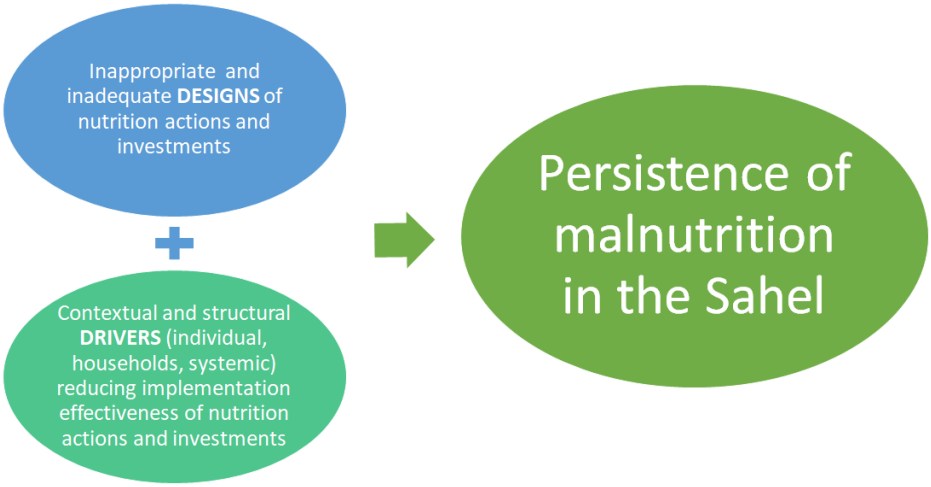

Figure 1. *High-level understanding of persistence of malnutrition in the Sahel. Source: NRF.*

The present study identifies the contextual drivers that may explain the effectiveness of nutrition programming on reducing undernutrition, to gain insights into the circumstances under which interventions are implemented. It consists of three complementary components:

- Systematic review of published evidence on the undernutrition drivers in the Sahel.
- Machine learning analysis of geocoded survey and environmental data.
- Case-study including participatory research with stakeholders and communities in Burkina Faso and Niger.

The study is complementary to the NRF study: "Understanding persistence of malnutrition in the Sahel. Study B: Assessing designs of nutrition initiatives", which analysed gaps in the design of multisectoral nutrition interventions in six West African Sahelian countries (Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal),

[1] This information is detailed on the section "Financing gaps for the prevention and treatment of malnutrition in the Sahel persist" of the UNICEF Advocacy Note "Addressing malnutrition in West and Central Africa: Addressing underlying vulnerabilities and ensuring sustainable financing", available here.

thus focusing on the structure/layout of intervention packages. Together, the two studies will produce evidence on how contextual drivers influence programme design and implementation, adding insights to strengthen the effectiveness of nutrition interventions and investments in the Sahel.

Introduction

The undernutrition burden in the Sahel

Undernutrition has been consistently observed in the Sahel and West Africa for decades [1,2], and its prevalence remains among the highest globally, although the burden varies considerably both between and within countries. The West and Central Africa region is one of the top three regions worldwide with the highest prevalence of underweight women (10%) and anaemia in women of reproductive age (44.7%)[3,4].

Anaemia is also high among under-five children in the region, with prevalence ranging from 66.3% in Chad to 79.0 % in Mali [5]. High (>20%) to very high (>30%) prevalence of stunting was observed in Burkina Faso, Guinea, Mali and Mauritania, and Cameroon, Chad, and Niger [4]. Likewise, an extremely high prevalence (>15%) of wasting in children under five years was observed in some areas of Burkina Faso, Chad, Mali, and Mauritania and a high prevalence (>10%) in larger areas of Burkina Faso, Mali, Mauritania, Niger, Nigeria, and Chad [4], meeting emergency levels, according to World Health Organisation (WHO) emergency thresholds. In fact, the estimated number of children under five years expected to suffer from global acute malnutrition or Global Wasting (moderate acute malnutrition and severe acute malnutrition) has been increasing steadily over the past years. Between 2015 and 2023, the number of children expected to suffer from moderate acute malnutrition increased from 1.8 million to 4.7 million, while the number of children expected to suffer from severe acute malnutrition increased from 0.8 million to 1.5 million [4].

Undernutrition can have immediate effects, such as increased susceptibility to infections and impaired physical and cognitive development, as well as medium-term effects, including stunted growth and delayed sexual maturation. In the long term, undernutrition can lead to chronic health issues such as cardiovascular disease, diabetes, and diminished cognitive function [6–9].

The multidimensional crisis of undernutrition, food insecurity and poverty

The intensity and configuration of vulnerabilities vary considerably across countries and subnational regions in the Sahel [10], although the region shares common characteristics. The Sahel is characterised by extreme climate variability and extreme temperatures (40–50ºC), which have been increasingly worsened in recent decades by climate change. Across its vast low-lying arid and semi-arid areas, a large share of the rural population is organised in pastoralist, agro-pastoralist, and farming communities, who have long adapted their production systems to these harsh agroecological conditions. However, the growing environmental pressures (e.g., desertification, droughts and floods), linked to broader conflicts and cross-border dynamics have intensified disputes over and insecure access to land, pasture, water and forest resources. Food systems are fragile and frequently under-resourced, leading to service disruptions, volatile food prices and deteriorating diet quality [1].

At the same time, rapid demographic change, urban migration and displacement further limit resilience. The region also faces long-lasting and ongoing cycles of shocks, crises and political instability, and institutions that could buffer shocks (agricultural/veterinary extension services, markets, health and WASH services, social protection) are passive. Seasonal peaks in disease risk (e.g., malaria, diarrhoea) compound these stresses, increasing vulnerability to undernutrition [1]. Moreover, the number of people in Emergency [Crisis Phase 4, according to the Integrated Food Security Phase Classification (IPC)] in the Sahel rose from 2 million in nine countries in 2024 to 2.1 million in 11 countries between June and August 2025. Most countries in the region

are following this upward trend, and only Chad, Mali, Mauritania and the Niger have fewer people in this phase [11]. The configuration and intensification of these characteristics vary considerably across countries and subnational regions in the Sahel.

The extent of global research on undernutrition drivers

The scientific community has developed frameworks illustrating the drivers of undernutrition, most of which derive from the "UNICEF conceptual framework of undernutrition," first developed in 1990, periodically updated [12,13], and adopted by the World Health Organisation [14]. This framework often guides nutrition programming and monitoring and evaluation (M&E) of interventions. However, as a universal valid framework, it does not capture contextual and specific features of all settings, such as the unique social and ecological environment of the Sahel. This can be a limitation to the understanding of the local drivers to better target policies and to better design M&E programmes. An updated version of the framework was designed in 2020 by Young et al. [1]. This update added specific characteristics of acute malnutrition in Africa's drylands, covering countries in the Sahel and West Africa [1], by adding "basic/systemic dimensions"[2] such as livelihood systems, formal and informal institutions, and environment and seasonality (Figure 2). This underscores the need to fine-tune frameworks to contexts showing distinctive characteristics [12,13].

Many studies are limited to cross-sectional design and used generalised (mixed) linear models for statistical analysis. Despite being widely used for causal inference, these models present limitations such as the allowance of only a small number of covariates and the fact that they do not properly assess multicollinearity [15,16]. Machine Learning methods help address some of these constraints by enabling the analysis of large, multi-source, geocoded databases and by capturing non-linear relationships and interactions across child, maternal, household, social and environmental factors [15–17]. Machine learning application to the study of drivers of undernutrition is a recent innovation, have been conducted mostly at the intra-country or country-level [18]. A meta-analysis identified 11 studies using machine learning methods to predict undernutrition, of which six are focused on Bangladesh. The remaining are focused on specific countries (Papua New Guinea; Rwanda, Ethiopia, Zambia) and one on sub-Saharan Africa [18]. Machine Learning models showed moderate to good performance metrics in predicting malnutrition using secondary Demographic and Health Surveys (DHS) data among children under five years [18], although the potential for these methods to analyse data from multiple sources have seldom been explored. There is also scarce qualitative evidence on the drivers of undernutrition, and particularly in West Africa and the Sahel [19]. This is a strong limitation, as qualitative or mixed-methods approaches, guided by dialogue across disciplinary boundaries, could offer a more systemic way to identify these complex and interacting drivers of malnutrition [20]. Such approaches may also help surface context-specific drivers and shed more light on the effects of factors often unmeasured in surveys or quantitative approaches, such as cultural and gender norms, societal changes, seasonality, social and institutional dynamics, conflict constraints, etc.

Systemic limitations in the African research environment may help explain why a comprehensive contextualised investigation of the drivers of malnutrition has been challenging the Sahel region. Funding is volatile and externally driven, with shifting donor agendas and short grant cycles that disrupt projects and constrain agenda-setting [21]. Moreover, institutional policies, cultural norms, and customs promote a 'siloed' research environment, which leads to frequent misunderstanding of research priorities: research funding bodies often assume there is sufficient knowledge to design interventions that address the principal underlying causes of malnutrition [22,23]. In addition, nutrition research in Africa has often a limited evidence base. Especially in the less economically developed countries such as Niger or Chad, research is sparse and primarily

[2] The term "systemic drivers" will be used throughout this report to refer to this set of political, economic, social, and institutional dimensions, corresponding to the "basic" level of causes in the UNICEF/Young framework.

concentrated on clinical topics. This reflects limited resources and technical capacity to conduct, write and publish applied nutrition research in the region [24].

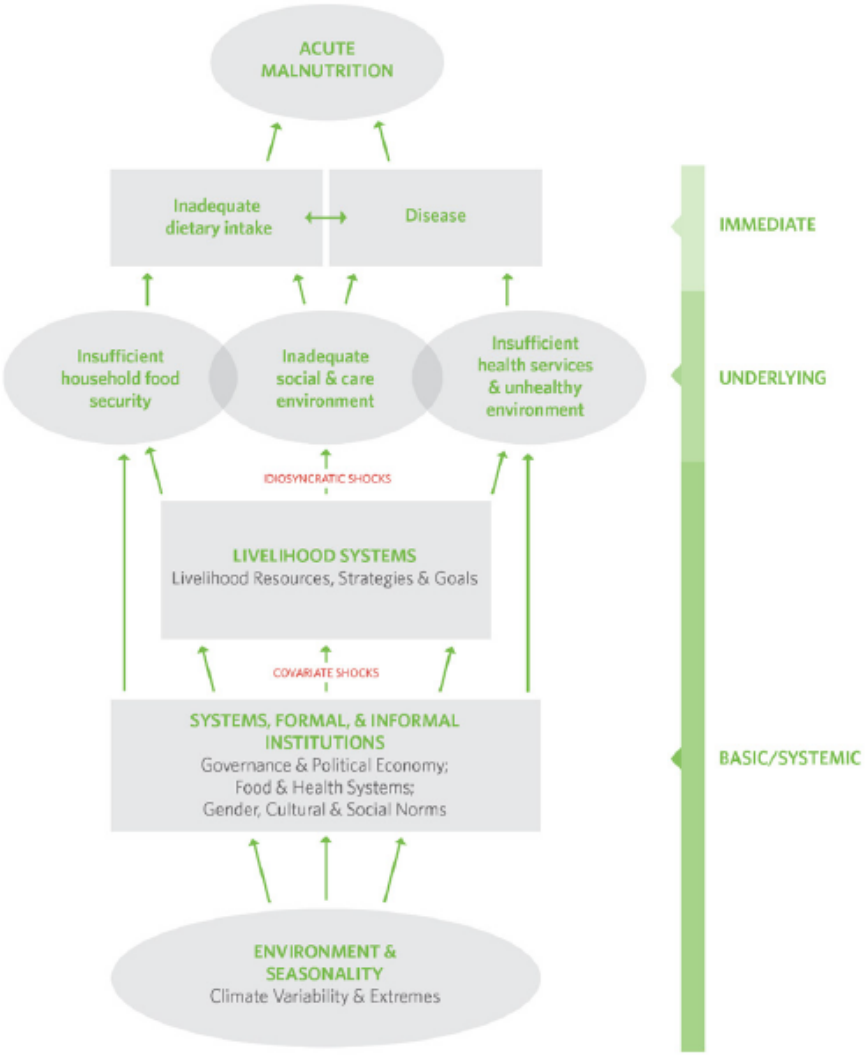

Figure 2.*Conceptual framework for the explanation of acute malnutrition in Africa's drylands. Source: Young, 2020.*

Defining the Sahel: political and geographical delimitations

There are several approaches to define the contours of what constitutes the Sahel, geographical and geostrategic, which reflect this region's unique nature as both a geographical and a political construct. Ecologically, the Sahel is defined as the semi-arid transition zone between the Sahara Desert to the north and the Sudanian savannas to the south, characterised by annual rainfall ranging between approximately 150 and 600 mm and strong seasonal temperature variations [25]. Politically defined boundaries often refer to the G5 Sahel countries (Burkina Faso, Chad, Mali, Mauritania, and Niger), an alliance that was established through a convention in 2014, to strengthen cooperation on security, governance, and development, and to promote stability and resilience across the Sahel region [26]. Some institutions and bodies apply broader regional scopes that also encompass neighbouring countries facing similar vulnerabilities. For example, the UN Integrated Strategy for the Sahel (UNISS) includes 10 countries (G5 and Cameroon, Guinea, Nigeria, the Gambia and Senegal)[3], and the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) includes 13

[3] Detailed information is available on the UNISS website: https://uniss-sahel.org/.

member states (G5 and Benin, Cape Verde, the Gambia, Guinea, Guinea Bissau, Ivory Coast, Senegal and Togo)[4].

The focus countries in this study are Burkina Faso, Chad, Mali and Mauritania, Niger and Senegal, ensuring consistency with the Study B. A broader geographical scope was, however, applied in the machine-learning analysis to ensure analytical consistency across comparable ecological and demographic contexts. The boundaries were determined based on spatial coherence and data availability, ensuring methodological robustness and relevance to the Sahelian context, and include 16 countries: Burkina Faso, Cameroon, Chad, Côte d'Ivoire, The Gambia, Ghana, Guinea, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo (Figure 3).

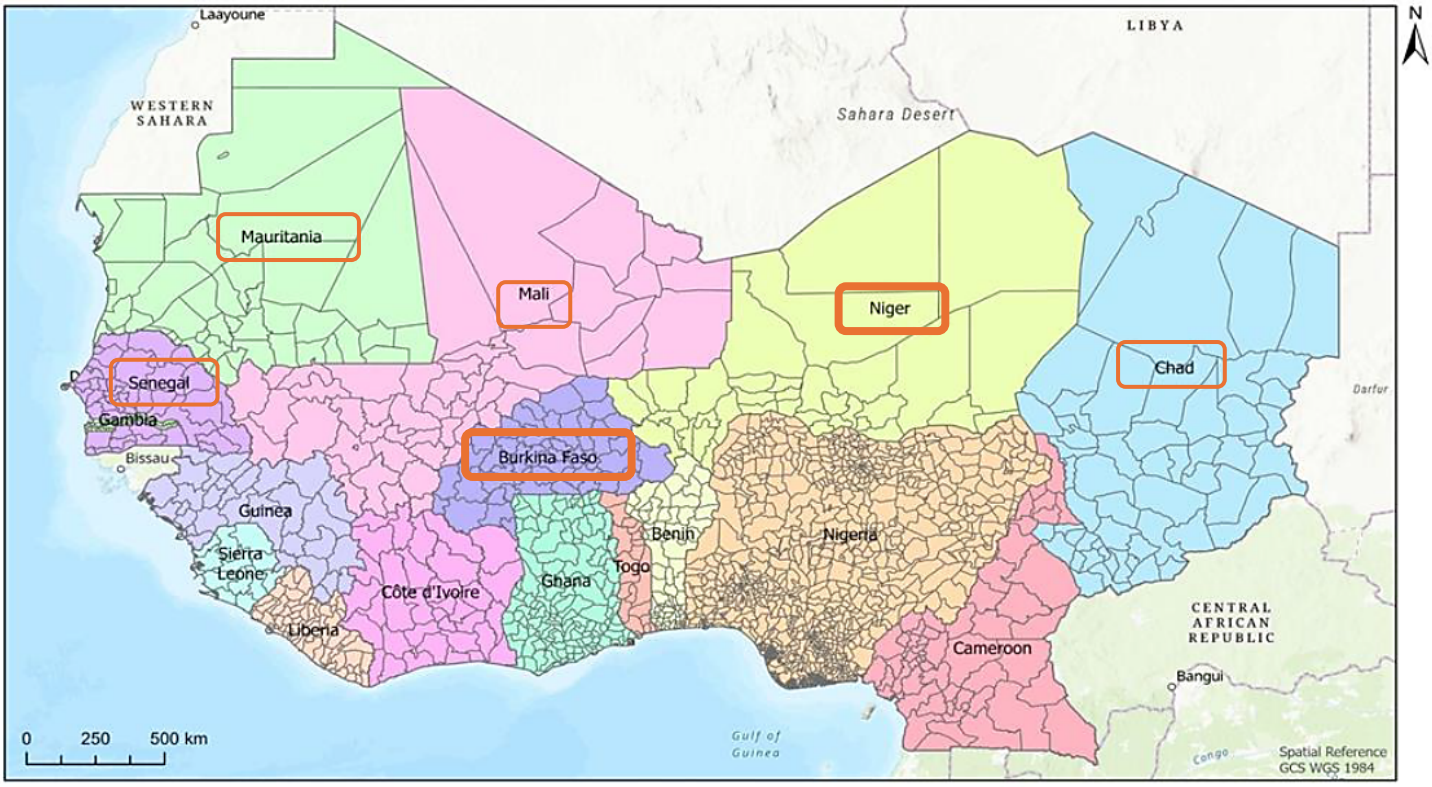

Figure 3. *Map representing the study area. The shaded-coloured countries represent the area included in the study using machine learning analyses. The countries outlined with orange boxes are the ones included in the systematic literature review. The qualitative study was conducted in Burkina Faso and Niger, highlighted with thicker outlines. Note: The boundaries and designations shown on this map are for analytical purposes only and do not imply official endorsement or acceptance by the European Union.*

Methodology

This study followed a mixed-methods approach to comprehensively identify the drivers of undernutrition among under-five children and women of reproductive age in the Sahel. In the first step, a systematic review was undertaken to map existing evidence from published scientific and grey literature. Building on these insights, machine learning models were further applied to secondary datasets, including DHS data and complementary geospatial and environmental data. This analytical step extended the insights from the systematic review by expanding the analysis beyond the published evidence, to capture additional contextual dimensions across immediate, underlying, and systemic levels influencing undernutrition outcomes in the

[4] Detailed information is available on the CILSS website: https://www.cilss.int/presentation-du-cilss/.

Sahel. The third component consisted of a qualitative study involving a desk review and documentary analysis, qualitative interviews, focus groups and workshops with experts and stakeholders to contextualise the quantitative findings. All methods of the third component were implemented in northern Burkina Faso, but in Niger, it was only possible to conduct the desk review and documentary analysis, as well as a national workshop with stakeholders (Figure 4).

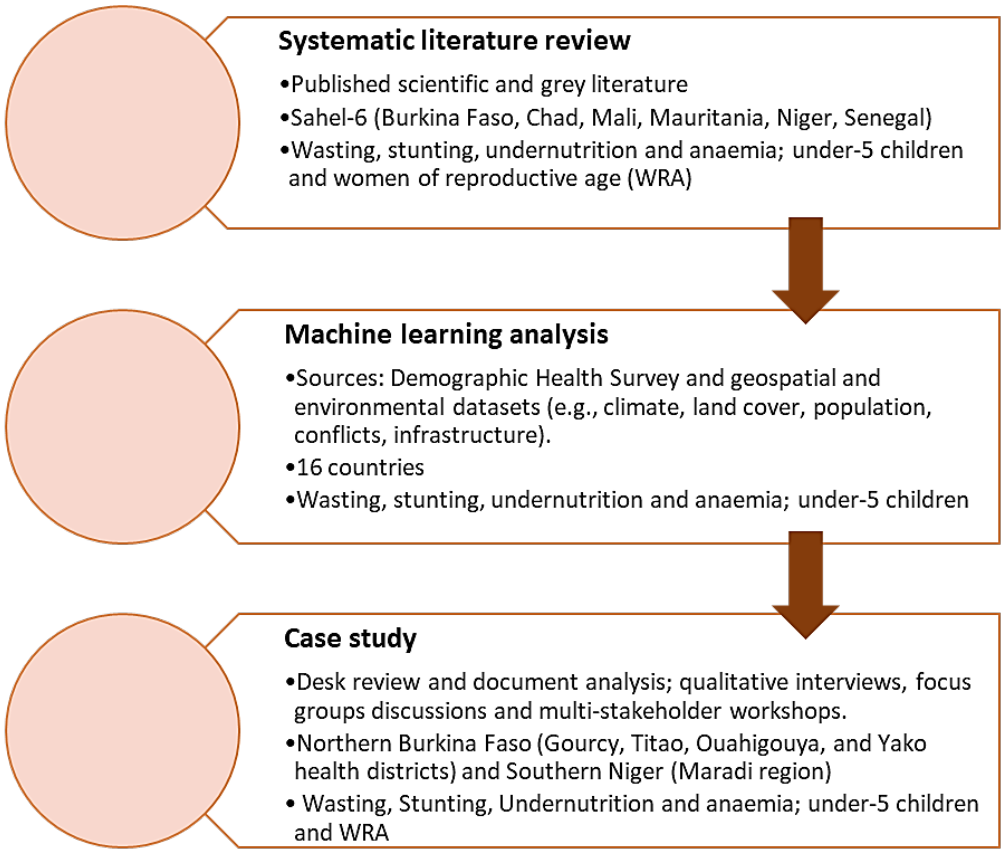

Figure 4. *Flowchart of the mixed-methods approach in this study.*

Component 1. Systematic review

This study component aimed to identify and review the drivers of undernutrition in the Sahel reported in the literature, to assess the extent of their representativeness, i.e., how well they reflect the contexts of the Sahelian countries. Below we provide a summary of the methodology. The detailed description is available in the study report [link to be added in the final published version of this report].

Study design

This systematic review is based on the ”best-fit” framework-synthesis approach [27,28]. Using an a priori framework for data analysis, it allows the combination of deductive (framework) and inductive (thematic) approaches, thus facilitating an interpretation contextualised by the UNICEF’s comprehensive conceptual framework of undernutrition.

Considering the number and heterogeneity of published studies on undernutrition drivers and specifically focusing on countries located in the Sahel (whether regarding outcomes, types of reviews, year of publication, etc.), existing evidence was summarised through a systematic review of (under/mal)nutrition-related published narrative and systematic reviews.

Given the particular focus of this study on the Sahelian region, the framework Acute malnutrition in Africa's drylands, developed by Young et al. [1] was the a priori framework selected to outline the findings of this systematic review (Figure 2).

This systematic review was first conducted in 2021, at the beginning of the study, with two subsequent updates performed in 2023 and 2025 to capture additional publications and ensure the analysis remained comprehensive and reflected the most recent evidence.

Eligibility criteria

The inclusion criteria were based on the following "Population, Intervention, Comparison, Outcomes and Setting (PICOS)" framework categories, expanded with timeframe and language.

Table 1. *Inclusion criteria, based on Population, Intervention, Comparison, Outcomes, Setting (PICOS), Timeframe and Language.*

	Detail
Population	Children under 5 years, infants less than 6 months and women of reproductive age (15-49 years)
Intervention/Exposure	Reviews reporting the prevalence of undernutrition and its drivers (excluding those addressing interventions and programmes related to undernutrition).
Comparison	No comparison groups were considered
Outcome	Stunting, wasting, anaemia, undernutrition
Setting	Sahel and individual countries (Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Djibouti, Eritrea, Ethiopia, Gambia Ghana, Guinea, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan)
Timeframe	Studies published until 31 May 2025
Language	English, French

Search strategy

1) Structured electronic search on the following databases: Medline, Clarivate Web of Science Core Collection, Cochrane Library, Cumulative Index to Nursing and Allied Health Literature (CINAHL) (CINAHL), International Bibliography of Social Science (IBSS), PsycINFO and African Journals Online (Table 2).
2) "Grey literature", through searching relevant organisations or development agencies' websites, namely: 3ie impact assessment, United Nations Children's Fund (UNICEF), United Nations Development Program (UNDP), Food and Agriculture Organisation of the United Nations (FAO), World Food Program (WFP), WHO, World Bank, African Development Bank, Save the Children, Action Against Hunger, Nutrition International, Global Alliance for Improved Nutrition (GAIN), International Food and Policy Research Institute (IFPRI), Nutrition Innovation Lab / Feed the Future, Bill and Melinda Gates Foundation.
3) Forward and backward citation tracking of all the eligible publications.

Screening and study selection

Studies yielded in the search were imported to Microsoft Excel spreadsheets into a single database and duplicates were removed manually. As such, a total of 1408 publications were screened through title and abstract, of which 1264 were excluded according to the eligibility criteria (Figure 5). After this initial selection of 144 articles, full texts of studies were reviewed for final inclusion. This process was undertaken independently by two researchers (GA and LG) and subsequently discussed for consensus.

At the stage of eligibility, 101 studies were excluded based on full-text assessment, namely those: not providing evidence on the relationship between potential drivers and the study outcomes or not reporting data on undernutrition drivers; intervention studies; not reporting on the outcomes of interest; not eligible types of publication or types of studies; duplicated publications. As such, 43 articles were included in the initial systematic review. The review was subsequently updated in 2023, incorporating additional publications identified through backward and forward citation tracking (n = 14), and an updated electronic search up to May 2023 (n = 4).

A second update was conducted in 2025, with an additional search up to May 2025 (n = 13) and incorporating additional publications identified through backward and forward citation tracking (n = 15) and hand searches (n=1). This update primarily aimed to capture more recent publications. Although the original eligibility criteria and search approach (as described in 3.3. and 3.4.) were maintained, the analysis was refined to focus particularly on the Sahel-6 countries (Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal), to provide more context-specific insights. Overall, a total of 99 publications were included for data extraction, of which 46 addressed drivers of undernutrition in the Sahel-6 countries, which are the focus of the present review. Detailed information is shown in Figure 5.

Data extraction, synthesis and analysis

The data extracted included authors, year of publication, language, study setting, aim/objectives, type of publication, type of study, undernutrition outcome(s), population and the drivers identified.

Framework synthesis was conducted through the extraction of information on the drivers of undernutrition in a stepwise process: 1) first, the information was extracted in free text form; 2) then, the identified drivers were grouped according to the acute malnutrition in Africa's drylands framework dimensions of immediate, underlying and systemic causes of malnutrition (Figure 2).

Additionally, a descriptive quantitative analysis was conducted, providing absolute and relative frequencies of characteristics of the eligible publications (publication type, type of literature review, language, study setting and undernutrition outcomes) and all categories and dimensions of undernutrition drivers identified.

Further methodological details are available in the study report [link to be added in the final published version of this report].

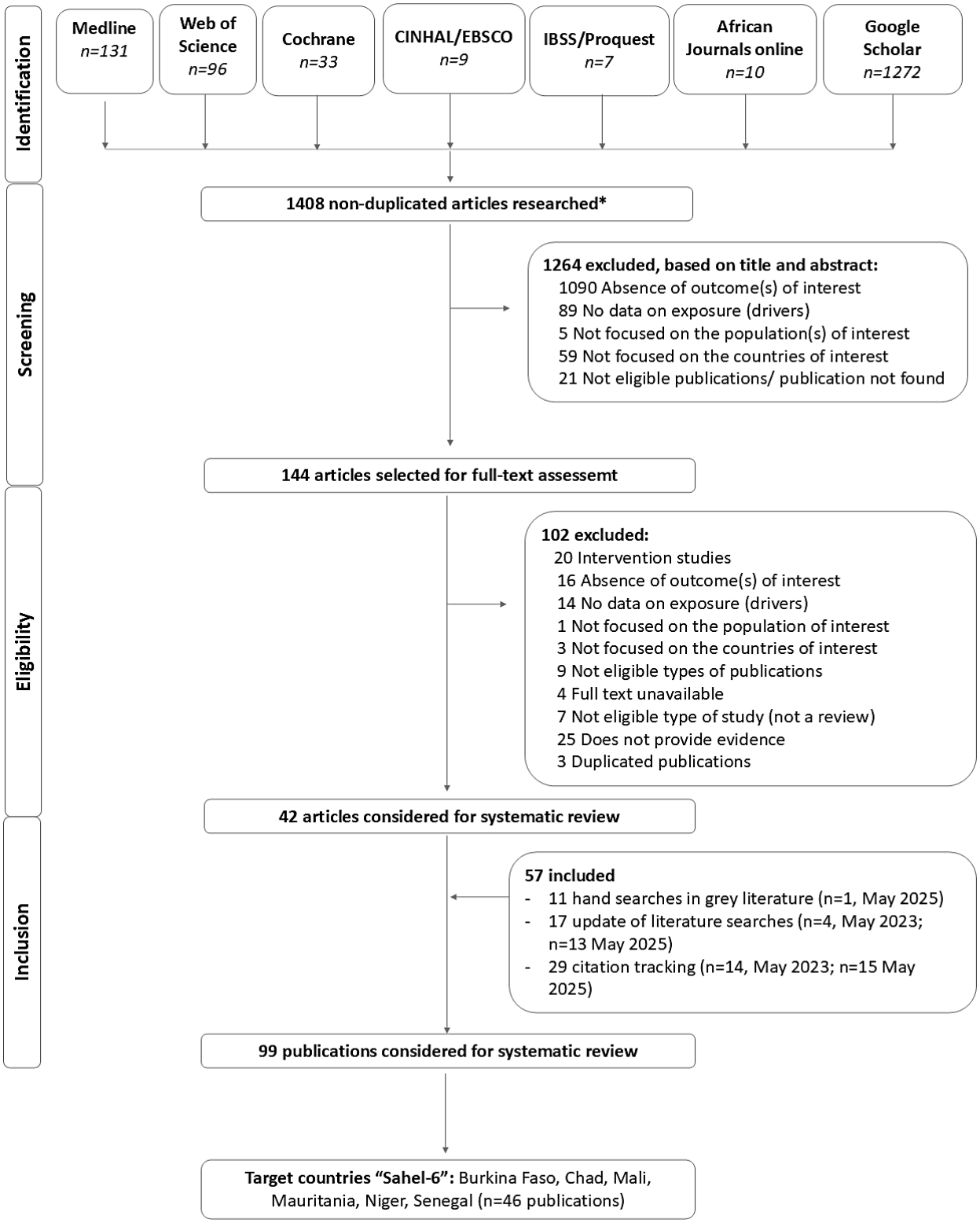

Figure 5. *Flowchart of search results.*

Component 2. Machine learning analysis

Study design

This cross-sectional study examined the determinants of child undernutrition in the Sahel region, using harmonised geospatial data and machine learning techniques. The analysis was conducted in three sequential stages: (1) construction of a standardised geodatabase, (2) data pre-processing and exploratory analysis, and (3) modelling and validation using machine learning algorithms. Below we provide a summary of the methodology. The detailed description is available in the study report [link to be added in the final published version of this report].

Data sources

Data compilation was based on the UNICEF/Young framework of undernutrition drivers, supported by the findings of the systematic literature review, and by relevant literature [29–33]. The DHS were the primary source for undernutrition outcomes and data on the immediate drivers of undernutrition, such as child and mother characteristics, household assets and birth conditions, among others. Additional data capturing the underlying and basic drivers, (e.g., environmental, climatic, demographic, and governance factors), were obtained from open-access repositories, namely the Armed Conflict Location & Event Data Project (ACLED)[34], Climatologies at high resolution for the earth's land surface areas (CHELSA) [35], European Space Agency [36], Malaria Atlas Project (MAP) space[37], Socioeconomic Data and Applications Center (SEDAC)[5], Spatial Production Allocation Model [38], Open Street Map (OSM) [39], World Resources Institute (WRI) [40], and Open Spatial Demographic Data and Research (WorldPop) [41].

Geodatabase

All retrieved data were integrated into a harmonised geodatabase developed for this study. DHS data were aggregated at the subregional level (administrative level 2) using sampling weights to preserve representativeness. To ensure spatial coherence, DHS clusters were re-projected and aggregated within their original subregional boundaries, accounting for the displacement introduced for confidentiality. External datasets were harmonised to the same coordinate reference system (WGS84) and spatial resolution (~1 km).

The resulting geodatabase encompassed 90 independent variables across 16 countries and 1,362 subregions, adhering to the FAIR principles (Findable, Accessible, Interoperable, Reusable). The full list of variables is available in Appendix 2.

Data pre-processing and exploratory statistical methods

Pre-processing of raw data was crucial to obtain a reliable data set and apply statistical analysis and machine-learning algorithms. This process implied dealing with inconsistent/incomplete data. After the conversion of raw data into a set of variables, the ones with missing values for one or more administrative areas were not included in the geodatabase, since performing spatial analysis with inconsistent spatial distribution leads to inaccurate results. Additionally, all the DHS clusters that did not provide spatial reference were excluded from the study.

All datasets were harmonised to a common spatial format and resolution, converting discrete indicators into continuous variables expressed as percentages. Data were then standardised using z-scores to enable comparability across variables. To minimise redundancy and improve model performance, multicollinearity was assessed through pairwise correlation coefficients and the Variance Inflation Factor . Variables showing strong correlations or Variance Inflation Factor values above the acceptable threshold were excluded from subsequent analyses.

Exploratory statistical analyses were conducted to scout the data structure and investigate trends in the data set. For this purpose, three linear statistical multivariate methods were applied: principal component analysis, partial least squares and k-nearest neighbours.

[5] Available at: https://sedac.ciesin.columbia.edu/. Inactive since July 2024

Modelling

The machine learning methods explored on this study were algorithms based on decision trees (Random Forest and Boosted Regression Trees, and on Artificial Neural Networks). These three were considered the most straightforward and robust to address the complexity of the data and obtain outputs able to explain undernutrition patterns. Separate models were developed for three specific outcomes: stunting, wasting, and underweight (among under-five children).

Model training and validation were conducted using five-fold cross-validation, randomly partitioning the dataset into training (80%) and validation (20%) subsets. The Relative Absolute Error (RAE) was used to assess predictive performance. Among the tested models, Random Forest demonstrated higher accuracy (RAE: 0.65 for stunting, 0.71 for underweight, 0.92 for wasting) and was selected for variable importance assessment.

Variable importance in the Random Forest model was determined through the mean decrease in accuracy metric. Variables explaining at least 75% of the cumulative variance of each outcome were retained as key predictors. The direction and magnitude of associations were examined through correlation analyses and spatial mapping. Comparative analyses across the three outcomes enabled the identification of shared and outcome-specific drivers of undernutrition.

Among the tested algorithms, Random Forest consistently showed better predictive performance and was therefore used to identify the most relevant drivers across outcomes. More detailed methodological procedures are available in the study report [link to be added in the final published version of this report].

Component 3. Case study

Setting and study design

This multi-method qualitative study was conducted in Burkina Faso and Niger aiming to understand the perspectives of local actors about the root causes of malnutrition in these countries/regions. In Burkina Faso, the study took place in the northern region, specifically in the Gourcy, Titao, Ouahigouya and Yako health districts. In Niger, the study covered the nine health districts that integrate the Maradi region, in the southern region.

The study was organised in several steps, as follows: 1) desk review, including a documentary analysis, conducted in both countries; 2) national and regional roundtable discussions with stakeholders in Burkina Faso and Niger to identify systemic drivers and inform the research tools; and 3) a qualitative survey (individual interviews and focus group discussions) conducted in the northern region of Burkina Faso only. Data collection took place between January and June 2025.

Desk review

This review aimed to map nutrition interventions conducted in the two study regions, as well as actors and results, identify reported contextual factors limiting programme performance and, ultimately, to refine the interview and group discussion guides.

The literature review covered all relevant sources relating to nutrition in the study areas. The following were analysed:

- Scientific articles published since 2005 [Google Scholar, PubMed, Scopus, Health InterNetwork Access to Research Initiative (HINARI)];
- Intervention reports, supervision reports, strategic documents, plans and guidelines from government structures, NGOs and partners;
- National and regional databases (DHS, SMART, local databases).

Roundtable discussions

Burkina Faso

A two-day round table was held on 20-21 February 2025 in Ouagadougou, Burkina Faso. The first day was devoted to the official launch ceremony for the study, chaired by the representative of the Secretary General of the Ministry of Health. The second day was devoted to a co-creation workshop aimed at identifying the systemic causes of persistent undernutrition in the northern region and in Burkina Faso and proposing solutions. The work was conducted in groups followed by plenary sessions.

The agenda and list of participants are included in the final report of the Burkina Faso Round [link to be added in the final published version of this report]. The participants included: representatives from the Northern Region; Ministry of Health departments responsible for nutrition; other sectoral actors (from the agriculture, livestock and environment sectors); international organisations and NGOs active in nutrition (FAO, WHO, UNICEF, ACF) and technical and financial partners.

Niger

The round table was held on 22–23 May 2025 at the Regional Directorate of Health and Public Hygiene (DRS/HP) in Maradi. This moment brought together representatives from the following institutions: Maradi Governorate; sultanates of Katsina and Gobir; DRS/HP of Maradi; Decentralised sectoral services (agriculture, livestock, education, environment, statistics, university); Guidan Roumdji, Dakoro and Madarounfa health districts; United Nations system (WHO, WFP, UNICEF) and national and international NGOs involved in the fight against malnutrition.

Qualitative survey

The qualitative study was conducted only in Burkina Faso. Purposive sampling was used to select participants for interviews and group discussions in Northern Burkina Faso, covering the community, health, regional and central levels. Participants were included because of their role in implementing nutritional interventions or their status as beneficiaries. Their participation was conditional upon signing an informed consent form.

Community level

The surveys were conducted in villages selected from health areas most affected by undernutrition, based on community health centres identified for their poor nutritional performance. Community participants included heads of households, mothers or guardians of children under five, pregnant women, community-based health workers, traditional healers, religious and traditional leaders, and representatives of NGOs or local associations. The number of interviews conducted in each category was guided by the principle of data saturation. Following the individual interviews, one focus group discussion was organised in each village.

Health facility level

In each selected community health centres, interviews were conducted with key health professionals, including the head nurse or nutrition focal point, the head of the maternity ward, and the paediatric manager. At the health district level, the chief district medical officer and the district nutrition focal point were interviewed. At the regional level, interviews involved the Regional Director of Health or his/her representative, as well as the regional nutrition focal point. In addition, a consultative meeting was organised with nutrition stakeholders identified through the literature review, including health workers and local NGOs.

Central level

At the national level, interviews were conducted with national nutrition programme managers, technical and financial partners and international NGOs active in nutrition (UNICEF, WHO, ACF, Save the Children, ALIMA, etc.).

The list of participants was finalised based on the findings of the literature review and integrating discussions between the research team and the NRF consultant. The sampling framework depicted in table 2 served as the basis for conducting surveys in the northern region of Burkina Faso.

Table 1. *List of participants in individual interviews and focus groups.*

Level	Participants	Planned number
Health facilities (n=6)	Health workers (2 per health facility)	n = 12
Villages (n=6)	2 women, 2 heads of household, 1 leader, 1 traditional healer, 1 community-based health worker, local non-governmental organisations/association (≈22 interviews) + 6 focus groups	n = 23 interviews + 6 focus groups
Decentralised structures	Schools, local authorities, agriculture, livestock farming, National Emergency Relief Council, etc.	n = 15
Districts (n=3)	Chief medical officers + nutrition focal points	n = 6
Region	Regional Health Directorate (2), NGOs/partners (3), local authorities (2)	n = 6
Central level	Programme managers & partners	n = 3

A total of 65 individual interviews and 6 group discussions were conducted, as well as a national consultative meeting. Additional details of this study are available here [link to be added in the final published version of this report] .

Data management and analysis

Data collection and analysis were guided by the conceptual framework adapted from the UNICEF/Young model (Figure 2). It informed the documentary review, the design of interview and discussion guides, and the subsequent thematic analysis.

All interviews and focus group discussions were audio-recorded (with consent), transcribed, and anonymised. Coding reliability was supported through double-coding of a subset and iterative codebook refinement. Findings were triangulated across documentary evidence, stakeholder workshops, and community-level accounts to enhance credibility and transferability.

Synthesis of findings

Component 1: Systematic review

Framework analysis: categorisation under the UNICEF/Young undernutrition framework

The results obtained, contextualised for the Sahel, suggest two adjustments to the subcategories of the framework:

1) Addition of a complementary dimension in “Immediate drivers” (individual characteristics).

Several individual characteristics among children (*e.g.,* age, sex, birth order, type of birth, low birthweight, birth size and preterm birth) and among mothers or caregivers (*e.g.,* age, early onset of childbearing, high parity/short interpregnancy intervals, first pregnancy, pregnancy or breastfeeding status and height) were identified as drivers of undernutrition. Such characteristics are not clearly identified in any of the dimensions integrating the UNICEF/Young Undernutrition framework. Given the relevance of these indicators in the Sahelian context, these were tentatively integrated within an “orphan category” named “individual characteristics” and then subdivided into “children” and “maternal” (as immediate drivers). This visualisation, which analytically disaggregates some dimensions of the comprehensive conceptual model, was instrumental to highlight overlooked explanatory aspects that are local and characteristic of the Sahel

2) Disaggregation of selected composite dimensions i) “Inadequate social & care environment” into “insufficient health services” and “unhealthy environment,” ii) “Food and health systems” into “Food systems” and “Health systems,” and iii) “Environment & seasonality” into “Climate variability and extremes” and “Seasonality.”

The Sahelian context presents distinctive characteristics at different demographic, societal and environmental levels, reflected in dimensions such as livelihoods, culture and gender, health and food systems, environment and seasonality, and political stability and conflicts. Although the UNICEF/Young framework accounts for these dimensions, during the process of categorising identified drivers from the literature using the best-fit approach, it was observed that the considerable number and diversity of drivers and indicators that emerged from the literature suggest that, in the Sahelian context, it might be pertinent to disaggregate some of the dimensions, in order to better group indicators that may be more inter-related and clarify on relevant causes of undernutrition in the region. Sahelian countries show specificities such as poorly-developed food systems (close to farming systems due to poor or absent linkages with the market)[42], health systems that are not embedded in the socioeconomic or natural environment, harsh agroecological conditions prone to extremes and climate shocks, or farming systems characterised by strong seasonality.

A proposed version for an updated UNICEF/Young framework accounting for the identified challenges is presented in Figure 6.

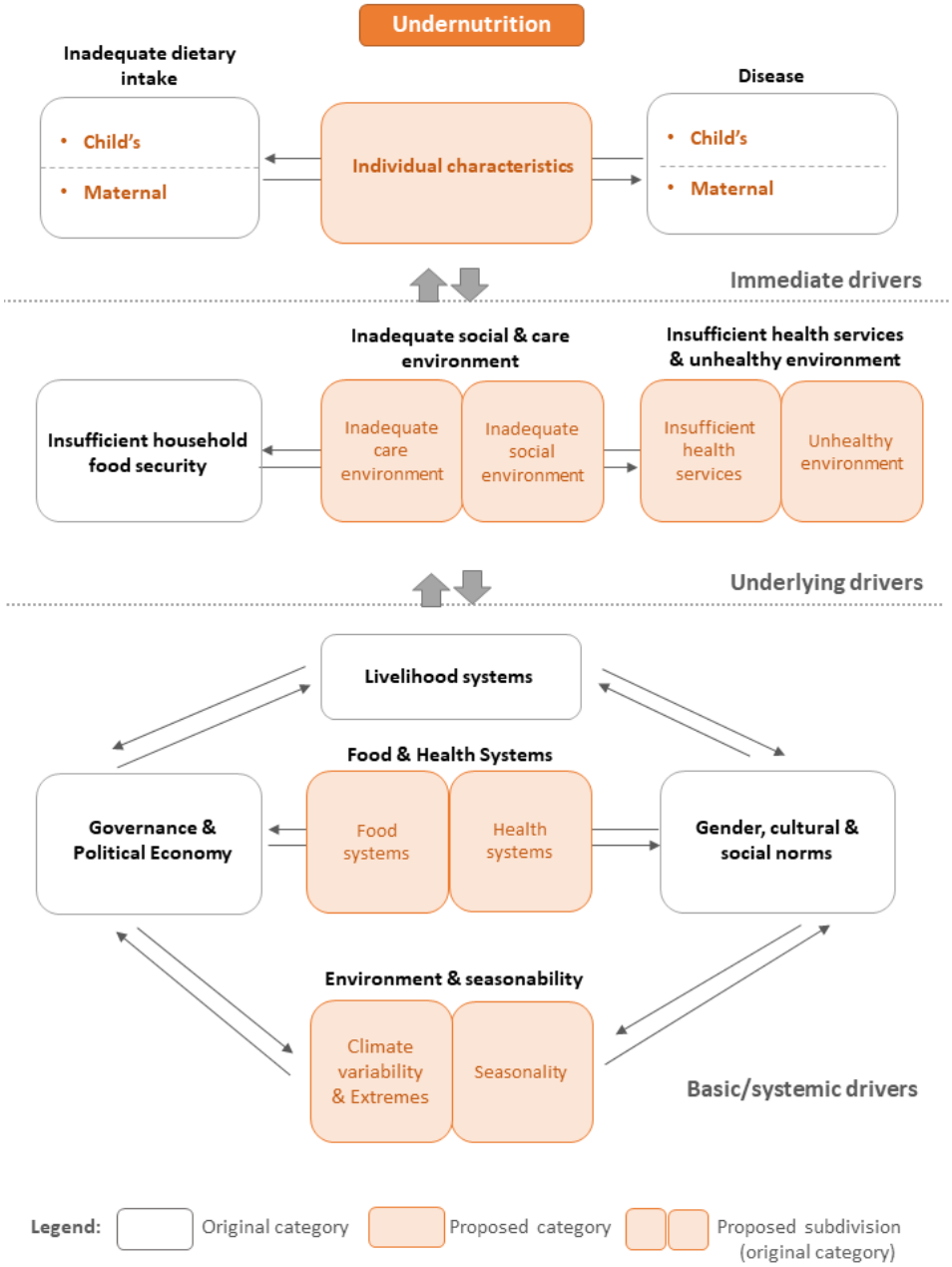

Figure 6. *Proposed representation of the framework of drivers of undernutrition contextualised for the Sahel.*

List of the reported drivers of undernutrition in the Sahel-6 countries

Across the 46 eligible publications focusing on the Sahel-6 countries (Burkina Faso, Chad, Mali, Mauritania, Niger, Senegal), a wide range of drivers of undernutrition were reported, across immediate, underlying, and systemic levels of the UNICEF/Young framework.

The literature is much more developed for stunting (the widest reported undernutrition outcome, in 60.9% of the publication) and child outcomes (followed by undernutrition - 45.7% - and wasting - 41.3%) than for anaemia among women of reproductive age. In fact, the greatest proportion of the Sahel-6 publications were focused on children (91.3%) (Table 3). The geographical coverage of the publications is also unbalanced across the Sahel-6 countries: publications were mostly focused on Burkina Faso (71.7%), Mali (52.2%) and Senegal (47.8%); Mauritania (6.5%), Chad (23.9%) and Niger (32.6%) were underrepresented.

Table 3. *Characteristics of all publications reporting drivers of undernutrition in Sahel 6 countries (n=46).*

	Sahel-6 countries' publications (n=46)	
	n	%
Publication type		
Scientific paper	45	83.3
Technical/discussion paper	5	9.3
Technical report/publication	3	5.6
Book chapter	1	1.9
Language		
English	45	97.8
French	1	2.2
Type of literature review		
Systematic Review	36	66.7
Narrative review	18	33.3
Study setting		
LMIC, including in the Sahel	34	73.9
Africa, including in the Sahel	7	15.2
Only countries in the Sahel	5	10.9
Outcome*		
Stunting	28	60.9
Undernutrition**	21	45.7
Wasting	19	41.3
Anaemia	8	17.4
Low birth weight	5	10.9
Target population		
Only children	42	91.3
Children and women of reproductive age	3	6.5
Only women of reproductive age	1	2.2

* The sum of all the categories is higher than 46, due to the fact that one eligible study could report more than one outcome. ** Undernutrition, as defined in the selected publications.

A total of 51 distinct drivers were identified in the Sahel-6 countries. Table 4 lists them, as well as their citation frequency, associated undernutrition outcome(s) and country(ies) in which they were reported. Systemic drivers were most frequently documented in the literature (71.7% of publications), followed by immediate drivers (60.9%) and underlying drivers were the least consistently reported (52.2%).

Most often described immediate drivers reflect poor dietary intake, infectious diseases, and maternal nutritional status. Among underlying drivers, food insecurity and poor infant and young child feeding practices were the most consistently reported. Systemic drivers included a broader set of domains, particularly low economic stability and education, governance and political instability (including conflict and displacement), and climate-related stressors such as climatic extremes and seasonality. Further details about country and outcome-specific observations for each undernutrition driver are available in Appendix 4 of the component 1 final report [link to be added in the final published version of this report].

Table 4. *List and citation frequency of identified drivers of undernutrition, organised by dimensions and categories, and contextualised in the Sahel (according to outcomes and countries where each driver was described) (n=46 publications).*

Drivers of Undernutrition in the Sahel					
Cause levels and categories	Drivers	Indicators	Contextualisation in the Sahel		
			Countries	Outcomes	No. citations
1.IMMEDIATE:					
1.1.Inadequate dietary intake					
1.1.1.Child	**Poor diet quality and quantity**	Inadequate dietary intake [19,43] or low dietary diversity (MDD) [19,44–50] Low Minimum Meal Frequency (<=3 meals/day, or below WHO MMF thresholds) [49,51] Low Minimum Acceptable Diet (MAD) [51,52]	BF, CHA, MAL, MAU, NIG, SEN	UND (child); STU; WAS	11*
1.2.Disease					
1.2.1.Child	**Infectious and parasitic diseases**	Infectious diseases [53] Infections: general [54] Malaria infection [46,55] Acute diarrhoea [56]	Sahel, MAL, NIG	UND (child), UNDW (child), ANA (child & WRA), WAS	5
	Gastrointestinal and absorption-related conditions	Gastrointestinal issues: Enteric pathogen infections, environmental enteric dysfunction [19,54,57,58], intestinal inflammation [59]	BF, MAL	UND (child), STU	5
	Nutritional status and deficiencies	Micronutrient deficiencies: general [45], Anaemia [60,61] Undernutrition: inadequate nutritional status [19], stunting [62,63], wasting [62,63]	Sahel, BF, NIG, SEN	STU, WAS, ANA (child)	6
	General compromised health status	Individual disease burden: disease, disability or morbidity status [19] Compromised physical activity [19]	BF, MAL, NIG, SEN	UND (child)	1
1.2.2.Maternal	**Infections**	Infections during pregnancy: malaria [45,64] Infections during lactation: *l. monocytogenes* [65]	MAL, SEN	WAS, ANA (WRA)	3
	Nutritional status and deficiencies	Undernutrition: during adolescence, during pregnancy [43], general [62,66] Maternal nutritional status: low BMI [45,49,67] Anaemia [67]	BF, NIG, SEN	UND (child & WRA), STU, ANA	6
	Mental health and stress	Exposure to (heat) stress during pregnancy [64]	MAL	STU	1
1.3.Individual characteristics					
1.3.1.Child	**Demographic**	Age [56,68] Sex (boys) [50,56,57,66,68,69]	BF, MAL, NIG, SEN	STU, UND (child), ANA (child)	6
	Birth-related	Multiple birth [45,56,68,70] Small for gestational age (SGA) [71]; low birth weight [62,68] Preterm birth [71]	BF, MAL, NIG, SEN	STU	6
1.3.2.Maternal	**Fertility and reproductive patterns**	Early onset of childbearing [66] High parity, short interpregnancy or birth intervals [45,55,56,62,66,68,70] First pregnancy (*primigravidae*) [55]	BF, MAL, NIG, SEN	STU, ANA (WRA), UND (WRA)	7
	Anthropometrics	Short stature [45,56,67]	BF, MAL, NIG, SEN	STU	3
2.UNDERLYING:					
2.1.Insufficient household food security					
	Household food insecurity	Household food insecurity [45,47,50,72], high acute food insecurity (household) [52] Food safety – household level [19]	BF, CHA, MAL, MAU, NIG, SEN	STU; UND (child); WAS;	7
2.2.Inadequate social & care environment					
		Poor feeding practices [46,50,62,66]			11*

Drivers of Undernutrition in the Sahel					
Cause levels and categories	**Drivers**	**Indicators**	**Contextualisation in the Sahel**		
			Countries	**Outcomes**	**No. citations**
2.2.1. Inadequate care environment	**Poor infant and young child feeding practices**	No or sub-optimal breastfeeding [19,45,52,53,73], including duration [45] or non-exclusive until 6 months [43,73] Formula feeding [19] Poor or inadequate complementary feeding practices [19,45], e.g., early introduction of complementary feeding [74]	Sahel, MAL, SEN	STU, UND (child), WAS	
	Unstructured caregiving	Stress of displacement [75]	CHA	UND (child & WRA)	1
2.2.2.Insufficient social services	**Limited access to social protection**	Constraints in the access to basic services [52] Access to cash or food transfers [19]	BF, MAL, MAU, SEN	STU	2
	Interrupted education	Interrupted or discontinued education for children and adults [50]	BF	STU	1
2.3.Insufficient health services & unhealthy environment					
2.3.1. Insufficient health services	**Low availability/ accessibility of health services**	Limited availability of healthcare services, systems or insurance; service disruption [19,46,50,52,66,76] Limited access to health centres or facilities or community resources [52,56,57] Low trust in community health workers [19] Few visits to doctor/other health professionals [45]	SAHEL; BF, CHA, MAU, NIG, SEN	UND (Child), WAS	9
	Low quality of reproductive, prenatal, maternal and child healthcare	Poor, limited access (e.g., fewer than 4 visits) or lack of prenatal care [19,45,55,56] Poor access to, or low quality of maternal care [66] Place of delivery outside a medical facility [45,70], lack of access to or absence of professional or skilled birth attendants [56] Limited access to newborn care [66] Limited access to family planning and reproductive health services [66], including use of contraceptive [45,66]	BF, MAL, NIG, SEN	STU, UND (child), ANA (WRA)	6
	Immunisation and disease prevention	Low immunisation status, coverage or incomplete vaccination [19,45], inadequate vaccine timing [68], including measles [46,52]	CHA, MAL, NIG	WAS, STU	4
	Reduced Health seeking behaviours	Reduced health-seeking behaviours [19]	BF, MAL, NIG, SEN	UND (child)	1
	High disease burden	High burden of childhood diseases [50,52] High malaria prevalence [76] High diarrhoea prevalence [52,76,77]	BF, MAL, SEN	WAS, STU	4
2.3.2. Unhealthy environment	**Poor water, sanitation and hygiene (WASH)**	Poor WASH conditions (general) [19,52,58,66] Poor access to improved sanitation [45,50,52,58,78] in the neighbourhood, including: lack of or lo-quality toilet facilities [56], no latrine ownership [58] or low % of latrines available [58]; open defecation [45,58,66] Poor hygienic practices: lack of hand-washing facilities, absence of soap and water near latrine; inadequate waste disposal in the community [58], poor household hygienic conditions [53], dirty floors [58]	SAHEL, MAL, SEN	STU, UND (child),	9
	Water insecurity	Low or poor access to clean water [43,45,50,76,77,79]	SAHEL, BF, MAL, SEN	UND (child), STU, WAS	6
	Environmental exposures	Exposure to indoor smoke from use of low-quality cooking fuels [58] Exposure to foodborne mycotoxins [58] Exposure to intestinal parasites [58,60]	Sahel, BF	STU, WAS	2
3. SYSTEMIC:					
3.1. Livelihood systems					

Drivers of Undernutrition in the Sahel						
Cause levels and categories		Drivers	Indicators	Contextualisation in the Sahel		
				Countries	Outcomes	No. citations
3.1.1. Livelihood resources, strategies & goals		**Financial resources and economic status**	Low socioeconomic status (household) [19,45,62,70] Low income, wealth or limited financial resources [45,68,77] Poverty or low wealth index (maternal or household) [56,79] Household assets [80] or household saving accounts [80]	SAHEL, BF, MAL, SEN	STU, UND (child)	10*
		Living conditions and infrastructure	Poor living or housing conditions [49,66] or poor household materials quality [56] Lack of access to electricity [80] Living in evacuation shelters or temporary housing [19] Poor access to roads [80]	BF, MAL, NIG, SEN	STU, UND (child)	5
		Education, human capital and communication	Low education or literacy level: household [19,62], maternal [45,66,68–70], paternal [45,56], or parental [66] Diminished household human capital [10]	SAHEL, BF, CHA, MAL, NIG, SEN	STU, UND (child & WRA)	9
		Livelihood strategies	Changes to livelihoods [10,46,79] Farming or pastoralist community [60,67]	SAHEL, BF	UND (child & WRA), ANA (WRA)	5
		Household structure and demographics	Large family size [69]	SEN	ANA (child)	1
		Location and population group characteristics	Rural residence [45,56,68–70,79] Indigenous population [56]	BF, CHA, MAL, SEN	STU, UND (child & WRA)	7
3.2.Systems, formal & Informal institutions						
3.2.1.Governance & Political Economy		**Economic governance**	National or regional development level [53,66,79] Low GDP per capita [56,68] Poverty [19,50] Economic/price shock or inflation [10,46,53], price volatility associated with seasonality [10] Out of pocket spendings [66]	SAHEL, BF, MAL, NIG, SEN	STU, UND (child & WRA), WAS	9
		Investment, spending and enabling environment	Corruption [19] Trust in legal systems [19] Enabling environment: capacity building [19], domestic resources mobilisation [19] Access (general) and humanitarian access constraints [46,52]	BF, MAL, MAU, NIG, SEN	UND (child), WAS	3
		Education	High illiteracy rate [66], low female education [56]	BF, MAL, SEN	STU, UND (child)	2
		Sociodemographics	Low employment rate [66] Female to male life expectancy [56] High population density or overcrowding [80] Migration [79], mountainous population migration [66] or massive population displacements [46,50,52] Urbanization rate [19,61]	Bf, CHA, MAL, NIG, SEN	STU, UND (child), WAS	9
		Political and civil stability	Civil Insecurity [52,53,76], high violence [10] Emergency preparedness [53] Political instability [10,19]	BF, CHA, MAL, NIG, SEN	UND (child& WRA),	5
		Human-induced shocks and disasters	Exposure to conflicts (armed, civil, communal or protracted): [10,46,50,52,56,75,81], including place of birth near or born during a conflict [56,58], prolonged exposure and/or severity [56,81] Exposure to epidemics: mortality epidemics [10], measles epidemic [76], cholera [52]	BF, CHA, MAL, MAU, NIG, SEN	UND (child& WRA), STU, WAS	9
3.2.2. Food & Health systems	3.2.2.1. Food Systems	**Agricultural and livestock production**	Low agricultural or crop production, crop yields or food harvest [10,46,66,72,79] Crop nutrient density [19]/ Nutritional value of crops (e.g. Iron content of soils and crops) [79]	Sahel, BF, CHA, MAL, SEN	STU, UND (child & WRA)	7

Drivers of Undernutrition in the Sahel						
Cause levels and categories		Drivers	Indicators	Contextualisation in the Sahel		
				Countries	Outcomes	No. citations
			Destruction of agriculture [75] Household agricultural/crop production [19] Low livestock production [10]			
		Water access	Low access to irrigation (household) [77]	BF, MAL, SEN	WAS	1
		Supply chains	Food shortage, scarcity or limited food stocks [19]	BF, MAL, NIG, SEN	WAS, UND (child)	1
		Food environment, food availability and access	Food environment disruptions [19] Limited access to supermarkets [80] Limited access to public infrastructure (e.g. markets) [80] Low dietary energy supply per capita [56] Food shortage, scarcity or limited food stocks [19,46]; Low food availability (population level) Low food affordability (population level) [19] Obesogenic environment [19]	BF, MAL, MAU, SEN	WAS, UND (child)	7
	3.2.2.2. Health systems	**Political economy of food**	Foreign economic embargos [75] Food as a weapon of war [75]	BF, CHA, MAL, NIG	UND (child & WRA)	1
		Governance and policies	Absence of a national food or nutrition policy [19]	BF, MAL, NIG, SEN	UND (child & WRA)	1
		System capacity and infrastructure	Low health system quality or robustness, or high health system degradation [52] Shortage of health workers [66]	CHA, SEN	UND (child), WAS	2
		Programmes and service delivery	Inadequate nutrition programming [19]	BF, MAL, NIG, SEN	UND (child & WRA)	1
3.2.3. Gender, cultural & social norms		**Limited women empowerment and agency**	Gender inequality [19,82], gender norms [60] Low women's empowerment [66,83] Low decision-making power (household level) [80,84]	Sahel, BF, MAL, NIG, SEN	STU, ANA (WRA), UND (child, WRA)	7
		Cultural norms and beliefs	Cultural norms or behaviours [85], including health and food beliefs, misconceptions and cultural practices [19,46] Child marriage [79]	SAHEL, BF, MAL, SEN	STU, UND (child)	3
3.3. Environment & seasonality						
3.3.1. Climate Variability & Extremes		**Environmental degradation and exposure to climate risks**	Climate vulnerability/change/warming/weather extremes/changes in humidity [19,52,86] Sea level rise, leading to low-elevation coastal zones and losses of sustainable water sources [79] Less-favoured agriculture areas [79] Altitude [56] Evapotranspiration [79] High levels of air pollution [79], higher carbon dioxide concentrations [79]	SAHEL, BF, MAL, SEN	STU, UND (child & WRA), WAS, UNDW	5
		Natural disasters and extreme events	Flooding [10,52,72,79,87] Droughts [10,56,72,79,87] Heatwaves or increased temperatures [56,64,72,79,87,88], including over time [88] Rainfall variability [10,72,79,86]: increased or excessive precipitation [56,88], low precipitation [79,88] or lower cumulative precipitation over time (~36 months) [79,88]	SAHEL, BF, CHA, MAL, NIG, SEN	UND (child & WRA), STU, WAS, ANA (child)	11*
		Ecosystem stressors	Pests [10]	BF, SEN	UND (child & WRA)	1
3.3.2. Seasonality		**Seasonal vulnerability**	Seasonality peaks in vulnerability [19,56,60,62,77] Wet season [77] Growing season [10]	BF, CHA, MAL, MAU, NIG, SEN	UND (child & WRA)	6

Legend: *BMI: Body Mass Index; GDP – Gross Domestic Product; MAD – Minimum Acceptable Diet; MDD – Minimum Dietary Diversity; MFF – Minimum Meal Frequency; WASH – Water, Sanitation, and Hygiene; WHO – World Health Organisation; WRA – women of reproductive age; Countries: BF– Burkina Faso, CHA – Chad, MAL– Mali, MAU– Mauritania, NG– Niger, SEN – Senegal; Outcomes: STU– Stunting, WAS– Wasting, UND– Undernutrition, UNDW– Underweight, ANA– Anaemia. *: Drivers reported by >20'% of the publications (n=46).*

Key takeaways to assist nutrition programming in the Sahel

Based on the findings from the systematic review of published literature, the following takeaways summarise observed patterns in evidence availability, reporting, and thematic emphasis:

1. Systemic drivers are widely cited in the literature, but empirical evidence informing programming in the Sahel remains limited

Poverty, education, gender inequality, governance, conflict, displacement and climate stress are frequently cited as key drivers of undernutrition. However, the evidence is fragmented and often derived from LMIC- or Africa-wide analyses, with limited Sahel-specific programming evidence.

2. Immediate drivers are consistently reported but narrowly framed

Immediate drivers related to dietary intake, infectious diseases, and maternal and child nutritional status are consistently reported across countries, particularly for child stunting. In contrast, evidence on immediate drivers for other outcomes, especially anaemia and undernutrition among women of reproductive age, is limited. As a result, immediate drivers relevant to outcomes beyond child growth failure are less well documented in the literature.

3. Underlying drivers are frequently underreported despite policy and programmatic relevance

Drivers related to care practices, access to and quality of health services, health-seeking behaviours, WASH, and social protection are reported less frequently than immediate or systemic drivers. This underrepresentation reflects limitations in data availability and survey design, constraining the evidence base for interventions that depend on service delivery and caregiving environments.

4. Evidence coverage is uneven across outcomes and countries

The literature provides relatively robust evidence for drivers of child stunting and for a limited number of Sahelian countries. Evidence on wasting, anaemia, and less-studied national contexts remains sparse. This limits generalisability and constrains cross-country inference within the Sahel.

5. Reported drivers reflect measurement practices rather than causal importance

The distribution of reported drivers is determined by the availability of standardised indicators, particularly those collected through DHS and similar surveys. Drivers that are difficult to quantify (e.g., psychosocial stress, institutional capacity, food systems and livelihoods) are therefore underrepresented. This reflects metrics and data constraints, but not necessarily lower causal relevance.

Several drivers widely reported in other LMIC contexts (e.g., as nutrient intake, sociocultural barriers, and nutrition knowledge) are absent from Sahel-focused reviews. This reflects gaps in documentation rather than contextual irrelevance, further reinforcing the need for triangulation of these findings with machine-learning analyses and qualitative evidence.

Component 2: Machine learning analysis

The machine-learning analysis included, in the initial steps, a process of harmonisation and pre-processing of all the data retrieved from the various sources. Of the initial 90 candidate variables, 66 were retained for modelling (Appendix 2).

Model performance and ranking of variables (drivers)

Predictive performance of the Random Forest method differed across undernutrition outcomes. The lowest relative absolute error was observed for stunting (RAE=0.65) and underweight (RAE=0.71), whereas wasting remained the least well predicted (RAE=0.92). This pattern suggests that wasting is influenced by a broader and more volatile set of interacting factors, reducing model precision compared with stunting and underweight.

Table 5 shows the most influential factors in the Random Forest models for stunting, wasting and underweight (the three dependent variables, or outcomes), colour-coded according to the driver category to which they belong: immediate – blue, underlying – green, and systemic – yellow). The selected variables explained at least 75% of the variance in each outcome. A total of 18 variables were retained for stunting, 20 for underweight, and 27 for wasting, indicating increasing model complexity for wasting.

Table 5. *Variable ranking for stunting, wasting, and underweight based on the results obtained with the Random Forest model*

Variables ranking	Stunting	Wasting	Underweight
1	Women who own a mobile phone, either alone or jointly (%)	Women literacy - higher than secondary or can read part or whole sentence (%)	Seasonal water supply variability (index)
2	Seasonal water supply variability (index)	Women who decide on health, purchases, and visits, either alone or jointly with partner (%)	Women who currently use any contraceptive method (%)
3	Women literacy - higher than secondary or can read part or whole sentence (%)	Mothers with antenatal care follow-up with ≥ 4 visits coverage (%)	Women literacy - higher than secondary or can read part or whole sentence (%)
4	Women who currently use any contraceptive method (%)	Mothers with antenatal care with skilled assistant (%)	Women who decide on health, purchases and visits, either alone or jointly with partner (%)
5	Households with refrigerator (%)	Seasonal water supply variability (index)	Grassland, lichen mosses or sparse vegetation (%)
6	People in the first or second wealth quintile - poor (%)	Grassland, lichen mosses or sparse vegetation (%)	Mothers with antenatal care with skilled assistant (%)
7	Women with first birth < 18 years old (%)	Children 3rd order or more (%)	Women who own a mobile phone, either alone or jointly (%)
8	Women who use a bank account (%)	Production/km^2 (ton/km^2 farming area)	Women with first birth < 18 years old (%)
9	Women who decide on health, purchases and visits, either alone or jointly with partner (%)	Households with livestock (%)	Women who are married or in a union (%)
10	Women who own a house, either alone or jointly (%)	Living children aged 12-23 months with no vaccine received (%)	People in the first or second wealth quintile - poor (%)
11	Human Modification Index	Households using solid fuel for cooking (%)	Women with BMI < 18.5 kg/m^2(underweight) (%)
12	Women who access none of the three media (tv, radio, newspaper) at least once a week (%)	Women who are married or in a union (%)	Mothers with antenatal care follow-up with ≥4 visits coverage (%)
13	Grassland, lichen mosses or sparse vegetation (%)	Women who use a bank account (%)	Mothers with iron supplementation during pregnancy (%)
14	Population density (nr. people/km^2)	Women currently employed (%)	Women who own a house, either alone or jointly (%)

Variables ranking	Stunting	Wasting	Underweight
15	Mothers with antenatal care with skilled assistant (%)	Women who currently use any contraceptive method (%)	Living children aged 12-23 months with no vaccine received (%)
16	Women who are married or in a union (%)	Arid land (% of area)	Women who access none of the three media (TV, radio, newspaper) at least once a week (%)
17	Living children aged 12-23 months with no vaccine received (%)	Road density	Women who use a bank account (%)
18	Living children aged 12–23 months who received all basic vaccinations (%)	Households with limited hand-washing facility (%)	Women with birth interval < 2 years (%)
19		Women who access all the three media (TV, radio, newspaper) on a weekly basis (%)	Households with refrigerator (%)
20		Households with radio (%)	Living children aged 12–23 months who received all basic vaccinations (%)
21		Women who access none of the three media (TV, radio, newspaper) at least once a week (%)	
22		People in the first or second wealth quintile - poor (%)	
23		Women with first birth < 18 years old (%)	
24		Households with agricultural land (%)	
25		Households with refrigerator (%)	
26		Children with any anaemia (%)	
27		Households using clean fuel for cooking (%)	

Legend: Variables are colour-coded according to the driver category to which they belong: immediate (blue), underlying (green), and systemic (yellow).

Cross-cutting drivers

Across all three outcomes, stunting, wasting and underweight, the Random Forest models repeatedly prioritised a core set of cross-cutting systemic and underlying drivers of undernutrition. Systemic drivers include indicators of women's human capital and agency (women's literacy, decision-making autonomy), household socioeconomic status (poverty proxy; bank account; media exposure) and environmental conditions (seasonal water supply variability; grassland/vegetation proxy). Underlying drivers reflected, essentially, reproductive health and service contact (contraceptive use; antenatal care with skilled assistance

and ≥4 visits), gaps in child preventive care (vaccination), as well as unhealthy household conditions (type of fuel/energy use, handwashing access).

The recurrence of these predictors across stunting, wasting and underweight reinforces that child undernutrition in the Sahel is influenced by interacting constraints across causal levels, rather than by isolated nutrition-specific factors.

Outcome-specific drivers

The models also differentiated outcome-specific profiles. For stunting, the top-ranked predictors included women's empowerment proxies (e.g., mobile ownership, literacy, contraceptive use), household infrastructure (e.g., refrigerator), and environmental stress (seasonal water variability).

For underweight, seasonal water supply variability ranked highest, alongside women's reproductive health and agency indicators (notably literacy, decision-making autonomy, access to reproductive health services, and control over productive and communication assets) and an environmental proxy (land cover).

Wasting required a substantially larger set of predictors to explain comparable variance, covering child health and prevention (e.g., vaccination gaps, child anaemia), household conditions and socioeconomic status (e.g., solid fuel use; limited handwashing access; livestock; poverty proxy), environmental stress (aridity; road density; land productivity), and women's human capital and agency (education, decision-making, union status, employment). This broader explanatory profile is consistent with wasting being associated with a wider range of child, household, and environmental conditions, reflecting greater sensitivity to instability and short-term stressors.

Key takeaways to assist nutrition programming in the Sahel

1. A limited number of cross-cutting drivers explain multiple forms of undernutrition

Despite the substantial number of variables explored in machine learning modelling, a small core set (women's literacy, decision-making autonomy, contraceptive use, access to antenatal care, and seasonal water variability) consistently explained variation across stunting, wasting, and underweight.

2. Women's empowerment emerged as a central and measurable driver

Indicators related to women's education, autonomy, reproductive health, and access to assets repeatedly ranked among the strongest predictors, reinforcing the prominence of gender and women's agency-related indicators in explaining variation in child nutrition outcomes.

3. Environmental and climatic constraints emerged as core determinants

Seasonal water supply variability and land characteristics were among the most influential drivers across models. This highlights the need to integrate nutrition objectives with water, climate adaptation, and land-use strategies.

4. Wasting reflects a more complex and fragmented risk structure

Compared with stunting and underweight, wasting was influenced by a broader and more diverse set of drivers, spanning child, maternal, household, and environmental dimensions. This complexity helps explain why wasting remains difficult to predict and prevent through single-sector interventions.

5. Results support integrated, multisectoral intervention packages rather than isolated actions

The convergence of health, gender, environmental, and livelihood-related drivers across outcomes suggests that nutrition programming in the Sahel is likely to be most effective when interventions are bundled and coordinated across sectors.

It should be noted, however, that machine learning models identify statistically influential drivers and spatial patterns but do not establish causality or capture lived experience. These findings are best interpreted in conjunction with the systematic review (Component 1) and qualitative evidence (Component 3).

Component 3: Case study

Overview of findings

The qualitative study conducted in Burkina Faso and Niger provided context-rich evidence that complements the findings from the systematic review and machine learning analysis. It highlighted how systemic and contextual constraints – insecurity, poverty, climate variability, gender norms and institutional weaknesses – interact to influence household decisions, programme implementation, and ultimately nutrition outcomes.

A set of key immediate, underlying and systemic drivers were identified which corroborate the systemic vulnerabilities identified in the systematic literature review and machine learning analysis.

> **Immediate drivers:** diarrhoeal disease, poor dietary diversity, suboptimal breastfeeding and complementary feeding practices, and closely spaced pregnancies due to limited access to or use of family planning.
>
> **Underlying drivers:** chronic food insecurity, seasonal food shortages, WASH deficits, low utilisation of health services, and limited use of locally available nutrient-rich foods. Participants also flagged misuse or redistribution of therapeutic foods, shaped by social norms around sharing and household food scarcity.
>
> **Systemic drivers:** widespread insecurity and population displacement, erosion of livelihoods, poverty, climate variability with recurrent poor harvests, entrenched gender norms constraining women's agency, and sociocultural beliefs influencing food allocation and child feeding (e.g. taboos surrounding eggs for children).

By bringing together the perceptions of diverse actors, the qualitative study offered valuable insights into why undernutrition persists in these settings, which have not yet been described in the literature. Three main takeaways emerged, which are described below.

Key takeaways to assist nutrition programming in the Sahel

Systemic vulnerabilities

Persistent undernutrition emerged as **the result of interconnected systemic vulnerabilities**, where immediate, underlying and systemic factors interact by constraining household choices and limiting the effectiveness of nutrition interventions. These systemic vulnerabilities converge around a set of mutually reinforcing dynamics:

Systemic constraints shaping household decisions: Poverty, weak health systems, and gender inequality were identified as core undernutrition determinants and were consistently confirmed and contextualised in the round tables and qualitative interviews. Participants further mentioned insufficient food availability, low uptake of family planning, and economic vulnerability. These constraints translate into daily decision-making through, for example, prioritisation of income generation over household consumption (e.g., selling eggs rather than eating them), resource control by household heads, and closely spaced pregnancies. Altogether, these findings underscore that systemic deprivation is not only a lack of resources, but a set of conditions that constrain the most fundamental household decisions.

Contextual shocks as amplifiers of vulnerability: insecurity and climate variability emerged not only as background conditions, but as central drivers that compromise livelihoods and disrupt service delivery. Specific examples mentioned include forced displacement, abandonment of agricultural land, and deterioration of health and social services, as well as the collapse of local milk production. The dual pressures of insecurity and mobility constraints significantly weaken state capacity and increase reliance on NGOs and local authorities.

Sociocultural norms as systemic determinants: sociocultural norms, often overlooked in the literature, emerged as highly influential in the round table discussions and individual interviews. First, a series of food taboos, gendered decision-making, early marriage and limited male involvement were identified. The qualitative findings further revealed how norms shape behaviour, including restrictions on consumption of certain nutrient-rich foods (e.g., eggs), the need for male approval for women to access health services, and the redistribution of therapeutic foods in alignment with social obligations.

These norms both influence and are influenced by demographic dynamics, contributing to high fertility and demographic growth. Insecurity-driven population displacement further amplifies the constraints affecting livelihoods, decision-making and service access. Together, these dynamics interact in ways that accentuate vulnerability, particularly in contexts affected by conflict and displacement, as highlighted during the Niger roundtable. It is important to acknowledge that these practices are not rooted in misinformation but are embedded in shared values and must therefore be integrated into programme design and communication strategies.

Limitations of the existing aid and support system: while international aid is essential in crisis-affected settings, it also faces coordination challenges, fragmentation, and constraints to sustainability in the Sahel. The case study highlighted unintended effects, such as the commercialisation of therapeutic foods and behaviours oriented toward maintaining programme eligibility. These dynamics demonstrate that external assistance, when insufficiently adapted to local contexts and incentive structures, may generate effects that partially undermine programme objectives.

Divergent interpretations among actors

Despite broad agreement on the nature of the challenges, **differences were observed in how the different actors interpret the causes of undernutrition and assign responsibility to address them**. These divergences have implications for coordinated action.

Divergent understandings of failure: The findings from the desk review and the narratives shared by the policy actors pointed to a systemic perspective, emphasising systemic weaknesses and misaligned or inadequate policies, such as some highlighted systemic and operational bottlenecks, such as supply chain issues, limited coverage in insecure areas or gaps in protocol compliance. In contrast, practitioners often attributed undernutrition to individual behaviours, particularly low literacy among mothers. The qualitative study situates the individual behaviours within incentive structures shaped by scarcity, insecurity, and aid dynamics, showing that practices often considered as “inappropriate” may be, in fact, rational coping strategies in a highly constrained environment. Without recognising and accounting for these divergent interpretations in intervention design, programmes are unlikely to be coherent or responsive to the realities in which they operate.

Diverging views on accountability: official discourse frequently frames frontline workers and health system actors as operating under insurmountable constraints, which reduced scrutiny of professional practices. At the same time, responsibility is often shifted to mothers, a dynamic that obscures systemic constraints and reduces opportunities to address and improve service-level gaps. This tension underscores the need for shared accountability across households, communities, and institutions.

Competing visions of appropriate solutions: Strategic actors tend to emphasise technical and institutional-level solutions such as improved coordination and financing mechanisms. Field-level perspectives prioritise pragmatic and context-adapted responses, including strengthening community engagement and promoting the use of local foods. Community realities, in turn, highlight the need for relationship-centred approaches that rebuild trust and address unintended incentive effects. These diverse perspectives highlight the value of coherent and multisectoral strategies that integrate technical, institutional and community-level solutions.

Towards a transformative roadmap

Confronted with these interconnected challenges, the evidence indicates that incremental adjustments to existing programmes are unlikely to be sufficient. A transformative approach is needed, which must simultaneously address systemic determinants, contextual constraints, behavioural incentives, and systemic inefficiencies, ensuring that interventions are aligned with the realities in which they operate.

Across the different interviews, discussions and evidence gathered in this study component, there seems to be a convergence among stakeholders on the need for multi-sectoral approaches, strengthened social protection, local capacity building, empowerment mechanisms, and sustained community engagement to improve nutrition outcomes in the Sahel. Figure 7 illustrates how responsibility for addressing undernutrition is distributed across multiple actors and delivery platforms, from households and organised communities to health services, line ministries, and development partners. It highlights that no single actor or sector can effectively address undernutrition in isolation: immediate determinants are shaped at household and community level, underlying constraints are mediated through service delivery and social protection systems, and systemic drivers require coordinated institutional and governance responses. This convergence reflects a shared recognition that fragmented, sector-specific actions are insufficient in contexts characterised by poverty, instability, and recurrent shocks, and that sustained nutritional improvements depend on coordinated engagement across these interconnected levels.

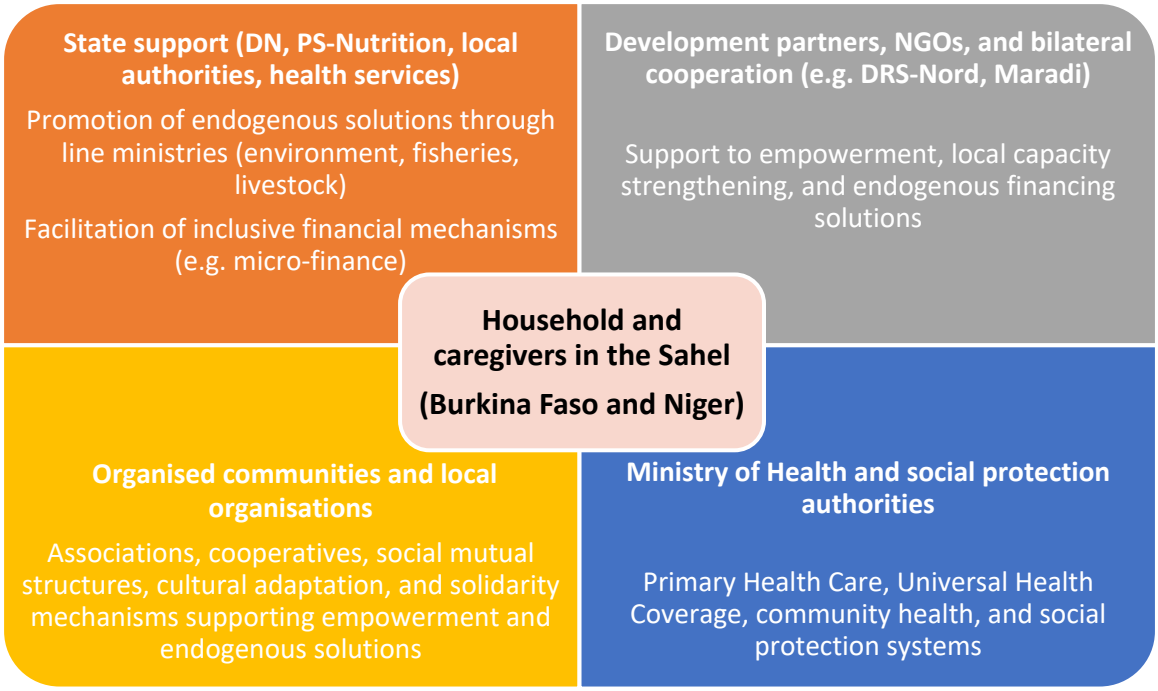

Figure 7. *Multi-level actors involved in addressing the drivers of undernutrition in the Sahel.*

These insights point to specific conditions that must be in place for a transformative nutrition response to be feasible and sustained in the Sahel:

Strengthening institutional capacity to manage complexity: there is a need for long-term institutional reforms. Strategic plans can only be impactful if they translate policy commitments into tangible actions backed by meaningful State engagement across all relevant sectors. Given the realities of insecurity and constrained governance, NGOs, local authorities, and community organisations act as essential intermediaries, supporting integrated approaches spanning health, agriculture, education, and social protection.

Revitalising community engagement and shifting from dependency to empowerment: strengthening community engagement should be a central pillar of effective nutrition programming. According to the key

findings, this involves engaging men and community leaders to shift sociocultural barriers; strengthening the competencies of frontline health workers through tools tailored to local contexts; and co-designing interventions with communities to anticipate unintended effects and encourage genuine ownership. Furthermore, strengthening communication approaches that frame therapeutic feeding as medical treatment rather than general food assistance is also essential. Together, these actions may contribute to align programme design with community realities and to reinforce agency rather than dependency.

Embedding nutrition within broader resilience and protection frameworks: isolating nutrition is ineffective in a context characterised by recurrent shocks. Integrating nutrition within Universal Health Coverage and Primary Health Care may help strengthening the continuity of care and institutional prioritisation. In parallel, resilience strategies should combine social protection, livelihood support, access to essential services, and climate-responsive agricultural measures, which together address both immediate, underlying and systemic drivers of undernutrition.

Conditions for a transformative approach: A transformative roadmap must concurrently address systemic determinants, behavioural incentives, and systemic inefficiencies. Only by tackling these dimensions in an integrated manner can stakeholders overcome the persistent barriers that have historically limited progress.

Cross-cutting insights on the persistence of undernutrition in the Sahel

Across the three study components, undernutrition in the Sahel emerged not because of insufficient technical knowledge on nutrition-specific interventions, but as the result of immediate drivers operating within persistent underlying and systemic constraints. A wide range interventions addressing diets, disease, and care are well established in the region, and particularly in Burkina Faso and Niger, yet their effectiveness is shaped by service instability, constrained caregiving capacity, livelihood insecurity, and environmental pressures. The interaction of these constraints helps explain why sustained reductions in undernutrition have remained difficult to achieve despite continued nutrition programming in the region.

The published evidence reflects, what is mostly routinely measured rather than the full range of drivers influencing nutrition outcomes in the Sahel. Findings from the systematic review show that published evidence is dominated by standardised indicators captured through population surveys. The machine-learning analysis confirms the relevance of several of these drivers but also identifies other cross-cutting factors, such as women's empowerment, household infrastructure, and environmental conditions, which are unevenly documented in the literature. Qualitative evidence further indicates that service disruptions, insecurity, and seasonal stress play a vital role in shaping diets, care practices, and health-seeking behaviours, despite remaining weakly represented in formal datasets.

Undernutrition is, thus, shaped by interacting combinations of drivers across immediate, underlying, and systemic levels rather than by single dominant factors. Machine-learning models highlighted non-linear relationships among predictors, and qualitative findings showed how households simultaneously navigate constraints related to food access, care, health services, livelihoods, and security. This convergence underscores that undernutrition reflects context-specific configurations of vulnerability.

Service delivery conditions emerged as a critical mediating factor between interventions and nutritional outcomes. Qualitative findings showed that interruptions in service availability, uneven service quality, staff shortages, and insecurity directly constrain care practices and health-seeking behaviours. These realities help explain why interventions that assume stable delivery platforms or sufficient caregiving capacity often generate limited or short-lived effects.

Poverty is present across multiple causal levels and cannot be understood as a single undernutrition driver. Poverty consistently shapes nutritional outcomes by constraining dietary quality, caregiving capacity, access to services, women's autonomy, and households' ability to absorb environmental and seasonal shocks.

Qualitative evidence further showed that many practices commonly interpreted as inadequate knowledge or suboptimal behaviours reflect adaptive coping strategies under constrained conditions. Caregivers make deliberate trade-offs in response to income insecurity, time scarcity, service interruptions, and seasonal pressures, prioritising short-term survival and livelihood needs over preventive practices. This embedded and adaptive role of poverty helps explain why interventions that focus narrowly on behaviour change or isolated income or food access measures often fail to deliver sustained improvements in diets, nutritional status and health.

Food systems constraints further mediate how immediate, underlying and systemic drivers translate into diets and nutrition outcomes. Limited market integration, seasonal and spatial variability in food availability, weak storage and processing capacity, and exposure to price volatility constrain access to diverse and nutrient-dense foods, particularly for poorer households. These food system characteristics interact with poverty, seasonality, and insecurity, reinforcing reliance on monotonous diets and reducing households' ability to buffer shocks. As a result, improvements in production, income, or knowledge do not consistently translate into improved diets, contributing to the persistence of undernutrition despite ongoing nutrition and food-related interventions.

Environmental, seasonal, and security-related pressures strongly influence household and service environments, introducing recurrent volatility that shapes nutrition-related decisions in practice. Machine-learning analyses identified water availability and water-related conditions as influential drivers across undernutrition outcomes, interacting with household infrastructure, caregiving capacity, and disease exposure. Qualitative evidence further showed how climatic variability, water stress, seasonal labour demands, displacement, and insecurity disrupt food availability, service continuity, and caregiving routines. Households and frontline workers respond through adaptive strategies that inevitably prioritise short-term stability and risk management over preventive actions. These coping logics reflect rational responses to constrained and uncertain conditions, rather than gaps in knowledge or motivation. Over time, such dynamics generate cycles of vulnerability that erode incremental programme gains and contribute to the persistence of undernutrition.

Recommendations and conclusion

Recommendations

The following recommendations synthesise and translate implementation-relevant insights emerging from the qualitative case study, together with findings from the systematic review and machine-learning analysis, to inform programme formulation and monitoring and evaluation in Sahelian contexts.

Strengthen the science-policy interface to support evidence-informed programming

In fragile settings, evidence used for decision-making often draws on data sources that may vary in quality, standardisation and contextual coverage. As shown by this study, the prominence of certain drivers in the literature reflects, in part, what is routinely measured, while locally-relevant undernutrition constraints, such as service disruptions, caregiving trade-offs, insecurity, seasonal stress and population dynamics, may be weakly represented in routinely used datasets.

Strengthening the science-policy interface could help address this gap by supporting more structured interpretation and triangulation of diverse evidence types, namely integrating quantitative analyses with qualitative and participatory evidence. This could help ensure that programme formulation, design and monitoring and evaluation reflect the interaction of immediate, underlying and systemic drivers identified in this study. To support this, future research efforts should prioritise:

- **Integrating quantitative and qualitative approaches through triangulation:** quantitative analyses help identify patterns and associations, while qualitative evidence is important to interpret, validate and contextualise the findings, particularly in settings characterised by non-linear relationships and implementation constraints.
- **Expanding the measurement of underlying and systemic drivers:** including care practices, health-seeking behaviours, institutional capacity, psychosocial stress, food systems, livelihoods, and seasonality, and differentiating drivers across nutrition outcomes (stunting, wasting, and anaemia) and population groups (children and women of reproductive age).
- **Systematically documenting lived experiences and service-level constraints:** particularly in underrepresented and crisis-affected Sahelian contexts (notably Chad, Mauritania and parts of Niger), to avoid extrapolating findings from a narrow subset of contexts and to better understand how systemic drivers translate into nutritional outcomes at community level.

Adopt integrated, multisectoral intervention packages grounded in local implementation realities

Evidence from all three study components indicates that undernutrition in the Sahel is shaped by interactions between service delivery, care practices, food environments and other systemic constraints such as livelihoods, insecurity, governance and environmental vulnerabilities. Qualitative findings further highlight that fragmented, sector-specific delivery can create implementation gaps at community level.

Programme formulation should therefore prioritise integrated, multisectoral intervention packages that explicitly account for interacting drivers across causal levels. In practice, this implies:

- **Addressing poverty as a cross-cutting constraint,** recognising that it simultaneous constrains diets, caregiving capacity, access to services, women's autonomy, and resilience to shocks. This could be done, for example by combining nutrition actions with measures that reduce systemic constraints on care, service access, and household decision-making capacity.
- **Placing women's empowerment and reproductive health at the centre of nutrition strategies.** Women's education, decision-making autonomy, reproductive health, fertility-related pressures and access to assets consistently influence caregiving practices, health-seeking behaviours and nutrition behaviours and outcomes. This could be operationalised, for example, by integrating nutrition strategies with interventions that strengthen women's agency expand access to reproductive health services, and reduce constraints linked to early marriage, high fertility, and unequal control over resources.

- **Aligning nutrition actions with climate, water, and seasonality-sensitive interventions,** acknowledging that environmental variability and seasonal stress influence seasonal labour demands, food availability, disease exposure and caregiving capacity. Programme formulation could therefore synchronise nutrition interventions with climate adaptation, water management, and seasonal risk mitigation strategies that address more predictable fluctuations in vulnerability.
- **Design models that reflect delivery constraints and caregiving trade-offs,** recognising that caregivers and frontline workers operate under persistent constraints, including insecurity, staff shortages, service interruptions and competing livelihood demands that influence both service provision and household decision-making. Nutrition programming could involve, for example, adopting more flexible and integrated delivery approaches, focused on decentralised or community-based modalities, and account for realistic assumptions about service continuity and caregiving availability in crisis-affected settings.

Strengthen monitoring and evaluation mechanisms to capture systemic effects

Existing monitoring and evaluation frameworks often prioritise short-term nutrition outputs while overlooking underlying and systemic drivers identified in this study. Monitoring and evaluation systems could, therefore, integrate indicators related to service quality, care environments, gender dynamics, and environmental stress, and combining routine data with qualitative monitoring. These approaches could support learning, accountability and evidence use at the science-policy interface for complex, multisectoral programmes and interventions.

Conclusion

The published evidence on the undernutrition drivers in the Sahel is uneven across countries and outcomes and strongly influenced by what is routinely measured in health and demographic surveys, with a predominant focus on child stunting. Undernutrition further emerged in this set of studies as the product of interacting constraints across cause levels rather than isolated drivers: machine-learning analyses identified a limited set of cross-cutting factors (women's empowerment, access to health and reproductive services, household conditions, and water- and climate-related stressors), and qualitative evidence illustrated how these constraints translate into adaptive, but nutritionally suboptimal, coping strategies at household level.

The present study argues that persistent undernutrition in the Sahel is not primarily explained by gaps in nutrition-specific knowledge or in intervention coverage. Immediate causes of undernutrition operate within underlying service constraints and broader systemic conditions, namely poverty, gender inequality, fragile institutions, environmental stress, and insecurity, that continuously influence diets, care practices, and health-seeking behaviours and outcomes. As a result, nutrition programmes are implemented in contexts characterised by instability and recurrent shocks, where improvements in the nutritional status are difficult to sustain over time. Together, these findings highlight the central role of systemic and contextual conditions in shaping nutrition outcomes, which contribute to the persistence of undernutrition in the Sahel.

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Appendixes

Appendix 1

Working definitions

Best-fit framework-synthesis systematic review: a mixed-methods type of systematic review that uses a deductive approach of mapping data from primary research studies onto a predefined framework (*a priori* framework), which represents the theoretical background of the issue under study [27,28]. As new data are incorporated and themes are derived, the framework is updated, resulting in the final framework being a mix of initial and revised themes [27]. This approach produces a rapid, transparent and pragmatic process of synthesis: a substantial amount of the data to be included in the review is often coded against the *a priori* framework and only the data that cannot be accommodated within the framework requires iterative interpretation using inductive, thematic analysis techniques [28].

Framework synthesis: a structured approach to organizing and analysing the data, involving the preliminary identification of a priori dimensions against which to map data from included studies and eventually the emergence of new dimensions/concepts [28].

Undernutrition outcomes: primary outcomes were considered any form of undernutrition among children, such as stunting, wasting, underweight, malnutrition or anaemia, or anaemia among women of reproductive age. Detailed definitions and indicators are described in table S1.

Table S2. *Definitions of outcome indicators, as used throughout the systematic review.*

Outcome Indicator	Definition / measurement
Stunted [89,90]	Stunting is a process of linear growth failure due to inadequate nutrition over a prolonged period and is worsened by recurrent and chronic illness, nutritional and psychosocial inadequacies. Stunting was defined as a height/length-for-age z score below two standard deviations (-2 SD) from the median of the World Health Organisation (WHO) Child Growth Standards. If a child is below minus three standard deviations (-3 SD) from the median of the WHO Child Growth Standards, then it is severely stunted.
Wasted [89–91]	Wasting reflects a process of weight loss due to an acute or recent nutritional deficit, although it can also persist for a long time. It usually occurs when a person has not had food of adequate quality and quantity and/or they have had frequent or prolonged illnesses. Wasting is often referred to as acute malnutrition or global acute malnutrition. Wasting was defined as a weight-for-height/length z score below two standard deviations (-2 SD) from the median of the WHO Child Growth Standards. Mid-upper arm circumference (MUAC) can be used as a rapid screening tool in resource-limited countries to identify wasting in children aged 6-59 months. WHO recommends using either or both weight-for-height/length z score or MUAC and the presence of nutritional oedema to assess the prevalence of acute malnutrition and for admission and graduation criteria for treatment programs [91]. MUAC measures the muscle mass of the upper arm. A flexible measuring tape is wrapped around the mid-upper arm (between the shoulder and elbow) to measure its circumference. MUAC should be measured to the nearest 0.1 cm.

Underweight [92]	A child who is underweight may be stunted, wasted, or both. Underweight was defined as a weight-for-age z score below two standard deviations (-2 SD) from the median of the WHO Child Growth Standards [92].
Undernutrition [92]	A group of conditions that includes wasting, stunting, underweight and deficiencies in vitamins and minerals. Undernutrition makes children much more vulnerable to disease and death [92].
Malnutrition [93]	Malnutrition refers to deficiencies, excesses, or imbalances in a person's intake of energy and/or nutrients. The term malnutrition addresses three broad groups of conditions: Undernutrition, micronutrient-related malnutrition (which includes micronutrient deficiencies - a lack of important vitamins and minerals - or micronutrient excess); and overweight, obesity and diet-related noncommunicable diseases (such as heart disease, stroke, diabetes and some cancers)[93].
Anaemia [89,94]	Anaemia is defined as a haemoglobin concentration below a specified cut-off point. The cut-off point depends on the age, sex, physiological status, smoking habits and altitude at which the population being assessed lives. Anaemia **in children 6–59 months** is defined as a haemoglobin concentration <110 g/L at sea level, moderate anaemia of haemoglobin 70–99 g/L and severe anaemia of haemoglobin < 70 g/L. Anaemia **in women** is defined as a haemoglobin concentration <110 g/L at sea level, and in non-pregnant women as a haemoglobin concentration <120 g/L.

UNICEF/Young framework of undernutrition: most frameworks illustrating the drivers of undernutrition derive from the "UNICEF conceptual framework of undernutrition," first developed in 1990 and regularly updated [8,9]. It was also adopted by the WHO [10]. This framework acknowledges the causality of undernutrition at the micro (individual or household) and macro levels (local communities and society). The immediate causes of malnutrition capture the physiological reasons why an individual child becomes malnourished (related to food intake and disease). These reasons are driven by the underlying causes (inadequate household food security, care of women and children, and the health environment and access to health care), which are determined by the systemic causes of malnutrition. In the original UNICEF conceptual framework, the basic causes were primarily focused on "resources" (human, financial, and organisational), being the key determinants of reaching adequacy in the underlying causes [12–14]

Young et al. proposed an updated version of this framework [1], by adding dimensions related to characteristics of acute malnutrition in Africa's drylands (covering countries in the Sahel and West Africa) [1]. To account for these phenomena, the framework of *acute malnutrition in Africa's drylands* includes systemic dimensions such as, *inter alia*, gender, livelihoods, and environment and seasonality (Figure 2). Despite the framework focuses on acute malnutrition (wasting), it was adequate, given that, according to prior literature, drivers of stunting and wasting tend to be derived from the same causes (*i.e.*, conceptual dimensions) [95].

Appendix 2

Table S1. *Comprehensive list of the independent variables explored in the machine learning study (n=90).*

LEVEL	DIMENSION	CATEGORY	INDICATOR	VARIABLE NAME
1. Immediate drivers	Diet Children	Child Dietary Diversity Score	Children < 5 with minimum dietary diversity (%)	ch_mdd
		Child Minimum Acceptable Diet	Children with minimum acceptable diet (%)	ch_mad
		Child Minimum Meal Frequency	Children with minimum meal frequency (%)	ch_mmf
	Health status Children	Child prevalence of anaemia	Children with any anaemiaanaemia (%)	ch_anaemia
		Child disease symptoms	Children with ARI symptoms at any time in the 2 weeks preceding the survey (%)	ch_ari
			Children with fever at any time in the 2 weeks preceding the survey (%)	ch_fever
			Children with diarrhoea at any time in the 2 weeks preceding the survey (%)	ch_diar
	Individual characteristics Children	Sex of child - male	Male children (%)	ch_male
		Sex of child - female	Female children (%)	ch_female
		Child birth weight	Children birth weight < 2.5kg (%)	ch_small
		Child vaccination	Living children aged 12–23 months who received all basic vaccinations (%)	ch_all_vac
			Living children aged 12-23 months with no vaccine received (%)	ch_no_vac
		Childbirth order number	Children 3rd order or more (%)	ch_order3
	Individual characteristics Mothers/women	Birth interval	Women with birth interval < 2 years (%)	wm_birth2
		Mother age at first birth	Women with first birth < 18 years old (%)	wm_birth18
	Health status Mothers/Women	Mother nutritional status (BMI)	Women with BMI < 18.5 kg/m^2 (underweight) (%)	wm_thin
		Prevalence of anaemia in women	Women with any anaemia (%)	wm_anaemia
2. Underlying drivers	Childcare environment	Age appropriately breastfed - adherence towards WHO optimal feeding recommendations	Children age appropriately breastfed (%)	ch_appbf
	Health services Mothers/Women	Access to antenatal care	Mothers with antenatal care with skilled assistant (%)	wm_skill
		Access to antenatal/prenatal care/ Antenatal visits/Antenatal care 4+ visits	Mothers with antenatal care follow-up with >=4 visits coverage (%)	wm_4visits
		Iron supplementation during pregnancy coverage	Mothers with iron supplementation during pregnancy (%)	wm_iron
		Drugs for intestinal parasites	Mothers who took drugs for intestinal parasites (%)	wm_paras
		Problems accessing health care	Women with at least one problem accessing healthcare, either permission, money, distance or not wanting to go alone (%)	wm_prob
		Knowledge of any contraceptive method	Women with knowledge of at least one contraceptive method (%)	wm_fpknow
		Use of any contraceptive method	Women who currently use any contraceptive method (%)	wm_fpuse
	Health services Children OR	Access to health services	Walking only travel time to water (minutes)	tt_wp_wo

LEVEL	DIMENSION	CATEGORY	INDICATOR	VARIABLE NAME
	mothers/women		Motorised travel time to water (minutes)	tt_wp_mo
3. Systemic drivers	Individual characteristics Women	Marital status	Women who are married or in a union (%)	wm_union
		Literacy	Women literacy - higher than secondary or can read part or whole sentence (%)	wm_liter
		Occupation	Women currently employed (%)	wm_employ
			Women with agriculture/manual occupation (%)	wm_agriman
		Media exposure	Women who access all the three media (TV, radio, newspaper) on a weekly basis (%)	wm_media3
		Media exposure	Women who access none of the three media (tv, radio, newspaper) at least once a week (%)	wm_nomedia
	Women empowerment	Ownership of assets	Women who use a bank account (%)	wm_bank
		Ownership of assets	Women who own a house, either alone or jointly (%)	wm_house
		Ownership of assets	Women who own a land, either alone or jointly (%)	wm_land
		Ownership of assets	Women who own a mobile phone, either alone or jointly (%)	wm_mobile
		Decision-making	Women who decide on health, purchases and visits, either alone or jointly with partner (%)	wm_decide
	Religion	Religion	Women affiliated with Islam (%)	wm_muslim
			Women affiliated with Christianity (%)	wm_christian
			Women affiliated with traditional religions (%)	wm_tradit
			Women affiliated with other/no religion (%)	wm_no_relig
	Living environment	Access to electricity	Households with electricity (%)	hh_electric
		Handwashing facility	Households with basic handwashing facility (%)	hh_basic
			Households with limited handwashing facility (%)	hh_limited
		Type of cooking fuel	Households using solid fuel for cooking (%)	hh_solid_fuel
			Households using clean fuel for cooking (%)	hh_clean_fuel
	Livelihood systems - socioeconomic status	Socioeconomic status	People in the first or second wealth quintile - poor (%)	hh_poor
	Livelihood systems - Household assets	Household assets	Households with TV (%)	hh_tv
			Households with radio (%)	hh_radio
			Households with mobile or telephone (%)	hh_phone
			Households with refrigerator (%)	hh_fridge
			Households with car or motorcycle (%)	hh_motocar
			Households with agricultural land (%)	hh_agriland
			Households with livestock (%)	hh_livestock
	Livelihood systems & resources	Access to health services	Walking only travel time to healthcare facility (minutes)	tt_hc_wo
			Motorised travel time to healthcare facility (min)	tt_hc_mo

LEVEL	DIMENSION	CATEGORY	INDICATOR	VARIABLE NAME
	Governance & Political Economy	Poverty	Deprivation index	grdi
			Unimproved or no drinking water (% population)	udw
			Unimproved or no sanitation (% population)	usa
		Socio demography	Population density (n° people/km²)	pop_dens
		Civil Insecurity	Nr. victims from conflicts per year over 21 years (n°/year)	fat_p_year
			Nr. Conflicts per year over the last 21 years (n°/year)	event_freq
	Food systems	Crop production	Production of agricultural crops (ton)	prod_total
			Production/km² (ton/km² farming area)	agr_prod
		Access to irrigation (household)/ Low water availability	Seasonal water supply variability (index)	sev
		Crop growing season	Growing season length (nr. days)	gsl
			Mean temperature of the growing season (ºC)	gst
	Environment & seasonality	Climate	Mean annual air temperature (ºC)	mat
			Annual precipitation amount (kg/m²)	ap
			Maximum monthly potential evapotranspiration (kg/m²)	max_po_ev
			Minimum monthly potential evapotranspiration (kg/m²)	min_po_ev
			Mean monthly potential evapotranspiration (kg/m²)	mean_po_ev
		Topography	Mean altitude (m)	DEM
		Land Use & Landcover	Net primary productivity (g carbon /m²)	npp
			Agriculture (% area)	agr_per
			Grassland, lichen mosses or sparse vegetation (%)	grass_per
			Forest + shrub (wildland) (% area)	forest_per
			Urbanised (% area)	urban_per
			Water bodies (% area)	water_per
			Wetlands (% area)	wetlan_per
			Rocks and sparsely vegetated (% area)	bare_per
		Human Intervention	Road density	road_dens
			Human Modification Index	hmts
		Extreme events	Arid (% of area)	arid_per
			low drought risk (% area)	low_per
			low/medium drought risk (% area)	lo_me_per
			medium drought risk (% area)	med_per
			medium/high drought risk (% area)	me_hi_per
			high drought risk (% area)	high_per

Variable name from DHS data indicates the group it represents: ch=children less than five years of age; wm=women; hh = household.

Appendix 3

Table S2. *List of selected variables for modelling (n=66) in the machine learning study*

LEVEL	DIMENSION	CATEGORY	INDICATOR	VARIABLE NAME
1. Immediate drivers	Diet Children	Child Dietary Diversity Score	Children < 5 with minimum dietary diversity (%)	ch_mdd
		Child Minimum Acceptable Diet	Children with minimum acceptable diet (%)	ch_mad
		Child Minimum Meal Frequency	Children with minimum meal frequency (%)	ch_mmf
	Health status Children	Child prevalence of anaemia	Children with any anaemia (%)	ch_anaemia
		Child disease symptoms	Children with ARI symptoms at any time in the 2 weeks preceding the survey (%)	ch_ari
			Children with fever at any time in the 2 weeks preceding the survey (%)	ch_fever
			Children with diarrhoea at any time in the 2 weeks preceding the survey (%)	ch_diar
	Individual characteristics Child	Sex of child - female	Female children (%)	ch_female
		Child birth weight	Children birth weight < 2.5kg (%)	ch_small
		Child Vaccination	Living children aged 12–23 months who received all basic vaccinations (%)	ch_all_vac
			Living children aged 12-23 months with no vaccine received (%)	ch_no_vac
		Childbirth order number	Children 3rd order or more (%)	ch_order3
	Individual characteristics Mothers/women	Birth interval	Women with birth interval < 2 years (%)	wm_birth2
		Mother age at first birth	Women with first birth < 18 years old (%)	wm_birth18
	Health status Mothers/women	Mother nutritional status (BMI)	Women with BMI < 18.5 kg/m2 (underweight) (%)	wm_thin
		Prevalence of anaemia in women	Women with any anaemia (%)	wm_anaemia
2. Underlying drivers	Childcare environment	Age appropriately breastfed - adherence towards WHO optimal feeding recommendations	Children age appropriately breastfed (%)	ch_appbf
	Health services Mothers/women	Access to antenatal care	Mothers with antenatal care with skilled assistant (%)	wm_skill
		Access to antenatal/prenatal care/ Antenatal visits/Antenatal care 4+ visits	Mothers with antenatal care follow-up with >=4 visits coverage (%)	wm_4visits
		Iron supplementation during pregnancy coverage	Mothers with iron supplementation during pregnancy (%)	wm_iron
		Drugs for intestinal parasites	Mothers who took drugs for intestinal parasites (%)	wm_paras
		Problems accessing health care	Women with at least one problem accessing healthcare, either permission, money, distance or not wanting to go alone (%)	wm_prob
		Knowledge of any contraceptive method	Women with knowledge of at least one contraceptive method (%)	wm_fpknow
		Use of any contraceptive method	Women who currently use any contraceptive method (%)	wm_fpuse
3. Systemic drivers	Individual characteristics	Marital status	Women who are married or with a partner a union (%)	wm_union

LEVEL	DIMENSION	CATEGORY	INDICATOR	VARIABLE NAME
	Women	Literacy	Women literacy - higher than secondary or can read part or whole sentence (%)	wm_liter
		Occupation	Women currently employed (%)	wm_employ
			Women with agriculture/manual occupation (%)	wm_agriman
		Media exposure	Women who access all the three media (TV, radio, newspaper) on a weekly basis (%)	wm_media3
		Media exposure	Women who access none of the three media (tv, radio, newspaper) at least once a week (%)	wm_nomedia
	Women empowerment	Ownership of assets	Women who use a bank account (%)	wm_bank
		Ownership of assets	Women who own a house, either alone or jointly (%)	wm_house
		Ownership of assets	Women who own a land, either alone or jointly (%)	wm_land
		Ownership of assets	Women who own a mobile phone, either alone or jointly (%)	wm_mobile
		Decision-making	Women who decide on health, purchases and visits, either alone or jointly with partner (%)	wm_decide
	Religion	Religion	Women affiliated with traditional religions (%)	wm_tradit
	Living environment	Access to electricity	Households with electricity (%)	hh_electric
		Handwashing facility	Households with basic hand-washing facility (%)	hh_basic
			Households with limited hand-washing facility (%)	hh_limited
		Type of cooking fuel	Households using solid fuel for cooking (%)	hh_solid_fuel
			Households using clean fuel for cooking (%)	hh_clean_fuel
	Livelihood systems - socioeconomic status	Socioeconomic status	People in the first or second wealth quintile - poor (%)	hh_poor
	Livelihood systems - Household assets	Household assets	Households with radio (%)	hh_radio
			Households with mobile or telephone (%)	hh_phone
			Households with refrigerator (%)	hh_fridge
			Households with car or motorcycle (%)	hh_motocar
			Households with agricultural land (%)	hh_agriland
			Households with livestock (%)	hh_livestock
	Livelihood systems & resources	Access to water	Motorised travel time to water (minutes)	tt_wp_mo
		Poverty	Unimproved or no drinking water (% population)	udw
		Socio-demographics	Population density (n° people/km²)	pop_dens
		Civil Insecurity	Nr. victims from conflicts per year over 21 years (n°/year)	fat_p_year
			Nr. Conflicts per year over the last 21 years (n°/year)	event_freq
	Food systems	Crop production	Production of agricultural crops (ton)	prod_total
			Production/km² (ton/km² farming area)	agr_prod
		Access to irrigation (household)/ low water availability	Seasonal water supply variability (index)	sev
		Land use & landcover	Grassland, lichen mosses or sparse vegetation (%)	grass_per
			Water bodies (% area)	water_per
			Rocks and sparsely vegetated (% area)	bare_per
	Environment & seasonality	Human intervention	Road density	road_dens
		Human intervention	Human Modification Index	hmts
		Extreme events	Arid (% of area)	arid_per
		Extreme events	Low drought risk (% area)	low_per
		Extreme events	Low/medium drought risk (% area)	lo_me_per
		Extreme events	Medium drought risk (% area)	med_per
		Extreme events	Medium/high drought risk (% area)	me_hi_per