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Research Article

Socio-Ecological Determinants of Sustainable Food Security and Health Outcomes Among Rohingya Refugees in Bangladesh: A Systematic Review and Meta-Analysis

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Abstract

Background: Rohingya refugees in Bangladesh face interconnected environmental, climatic, WASH, socioeconomic, food-system, nutritional, and health challenges affecting food security and health. However, evidence is fragmented, often examining environmental exposures, food security, nutrition, or health separately. An integrated socio-ecological synthesis is needed to clarify these relationships and identify knowledge gaps for humanitarian and public-health interventions. *Objectives:* This review and meta-analysis synthesized evidence on socio-ecological determinants of food security and health among Rohingya refugees in Bangladesh, examining environmental, climatic, WASH, dietary, nutritional, and health-related factors to identify key interconnections, evidence gaps, and implications for integrated interventions. *Materials and Methods:* The review followed the registered PROSPERO protocol (CRD420261507981) and PRISMA 2020 guidelines. Studies involving Rohingya refugees in Bangladesh were assessed against the protocol's population, exposure, outcome, and eligibility criteria. Records were screened, assessed for eligibility, and included studies underwent data extraction and methodological risk-of-bias assessment. Evidence covered socio-ecological factors, WASH and environmental health, food security, nutrition, and health outcomes. Quantitative synthesis was undertaken only when outcome definitions, exposure contrasts, and effect measures were sufficiently comparable. Reported measures included relative risks (RRs), odds ratios (ORs), and adjusted odds ratios (aORs), with 95% confidence intervals (CIs). Structured thematic synthesis and pathway analysis complemented the quantitative assessment. *Findings:* The search identified 74 PubMed records; 64 proceeded to screening after initial exclusions, 42 remained after duplicate removal, and 30 studies were represented in the review framework. Evidence linked environmental and socio-ecological factors with health outcomes, including temperature and gastroenteritis; WASH factors and cholera; seasonal and hygiene-related factors and pathogen-specific diarrhea; household food insecurity and adverse nutritional or health outcomes; dietary diversity and food-ration characteristics; and child undernutrition. Associations included cold temperature and gastroenteritis (RR 2.31, 95% CI 1.18–4.65), hot temperature and gastroenteritis (RR 1.78, 95% CI 1.24–2.56), household food insecurity and adverse outcomes (OR 2.86, 95% CI 1.74–4.71), and child undernutrition (aOR 3.14, 95% CI 1.88–5.26). Dietary diversity was associated with lower odds of the outcome examined (OR 0.46, 95% CI 0.28–0.76), while monotonous food rations were associated with higher odds (OR 1.92, 95% CI 1.23–3.01). Overall, findings suggest interconnected relationships among food insecurity, dietary constraints, WASH and environmental conditions, infectious disease risks, and nutritional vulnerability. *Conclusion:* Sustainable food security and health among Rohingya refugees require coordinated food, nutrition, WASH, environmental, and resilience-oriented interventions. Better-integrated evidence is needed to guide and evaluate these efforts.

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Keywords

Rohingya Refugees, Socio-ecological Determinants, Food Security, WASH and Environmental Health, Nutrition

1. Introduction

1.1. Global Context

Food security is a multi-dimensional state that encompasses food availability, access, utilization and stability, with sustainability and resilience increasingly recognized as critical to ensuring sufficient food access across time [1, 2]. Food insecurity is a specific vulnerability among refugee populations as displacement may affect livelihoods, purchasing power, eating patterns and availability to essential foods [3, 4]. Food insecurity is strongly associated to nutritional deficiencies and negative physical and mental health consequences, and environmental and WASH conditions may impact further food use, disease exposure and nutritional susceptibility [2, 5]. These interrelated pathways suggest that food security should not be viewed only as an indicator of food supply or household consumption, but rather as a larger socio-ecological predictor of health. Thus, the analysis of food security in conjunction with socio-economic, environmental, nutritional and health-related variables might provide a more holistic picture of the vulnerability of displaced communities.

1.2. Rohingya Refugee Context in Bangladesh

The Rohingya refugee crisis in Bangladesh has turned into a protracted displacement emergency with interlinked food, socio-economic, environmental, WASH and health vulnerabilities. Refugees continue to rely heavily on humanitarian food aid, with restricted livelihood prospects and declining purchasing power threatening to erode dietary diversity and household resilience [6]. Overpopulated settlements exert great stress on water, sanitation and hygiene (WASH) infrastructure, with evident problems in water treatment, sanitation, hygiene behaviors and disease prevention [7, 8]. A further socio-ecological strain is degradation of forest and land-cover, especially environmental degradation in the vicinity of settlements [9]. Seasonal and climatic factors may also alter health risks and there is evidence of links between air temperature and gastroenteritis among Rohingya populations [10]. These situations are occurring amid continued pressures on humanitarian health services [11]. Collectively, the evidence points to the need to include food insecurity, dietary quality, WASH conditions, environmental stressors, climate variability and health consequences as interrelated components of refugee vulnerability, deserving an integrated socio-ecological synthesis.

1.3. Knowledge Gap

Previous research among Rohingya refugees in Bangladesh has produced important evidence on food insecurity and livelihoods, nutritional status and dietary diversity, WASH, environmental degradation, infectious diseases and mental health, but these domains have been largely studied as distinct or partially overlapping problems [12-16]. Studies have shown livelihood constraints and food insecurity [12], nutritional and dietary vulnerabilities [13], WASH-related issues [14], environmental and biodiversity implications of settlement development [15, 16] and considerable psychosocial and health requirements [17, 18]. However, the evidence base is fragmented and the amount to which these variables interact across environmental, household, dietary and health pathways has not been adequately synthesized. In particular, there is a lack of integrated evidence relating environmental and WASH pressures with food access, dietary quality, nutritional vulnerability and consequent health effects in an integrated socio-ecological framework. Thus, the primary knowledge gap is not merely the absence of single studies but the absence of a systematic evidence-based synthesis that elucidates how interrelated socio-ecological elements converge to determine sustainable food security and health in Rohingya refugees in Bangladesh.

1.4. Study Rationale

Evidence from Rohingya communities reveals that environmental change, pressure on land-use, loss of biodiversity, food shortages, livelihood restrictions, WASH, and health vulnerabilities are linked elements of a complex displacement environment [14-16, 18]. Previous reviews have highlighted major health and human rights related vulnerabilities although individual research have focused on food security, environmental degradation and WASH independently [14, 15, 18]. However, evidence has not been synthesized adequately to quantify comparable correlations, and identify pathways linking socio-ecological variables with sustainable food security and health consequences. Therefore, a systematic review and meta-analysis are necessary to consolidate the scattered data, to evaluate the strength and consistency of quantitative relationships where statistically acceptable, and to identify sources of heterogeneity and evidence gaps. Complementary route synthesis can also provide context for the interaction between environmental, socioeconomic, food-system and health variables without the need to assume causality beyond the facts at hand. This integrated strategy builds a stronger evidence base for

coordinated humanitarian, public health, nutrition, WASH and environmental activities.

1.5. Review Objectives

This systematic review and meta-analysis aimed to:

1) To identify the major socio-ecological factors associated with food security and health among Rohingya refugees in Bangladesh.
2) To synthesize quantitative and qualitative evidence linking environmental, WASH, socioeconomic, livelihood, and food-system factors with food security, nutrition, and health outcomes.
3) To assess the strength, consistency, and variation of the available evidence across different determinants and outcomes.
4) To develop an integrated socio-ecological pathway showing how environmental, socioeconomic, food-system, and health factors are interconnected.

2. Materials and Methods

2.1. Protocol and Registration

This systematic review and meta-analysis was preemptively documented in the International Prospective Register of Systematic Reviews (PROSPERO) with registration number CRD420261507981. The protocol was designed to investigate the socio-ecological factors influencing sustainable food security and health results among Rohingya refugees in Bangladesh, encompassing environmental, WASH, socioeconomic, livelihood, and food-system elements. The documented protocol directed the criteria for eligibility, selection of studies, extraction of data, synthesis of evidence, and intended quantitative analyses when adequate comparable data were present. The evaluation was documented in alignment with the PRISMA 2020 guidelines to enhance methodological clarity, repeatability, and thorough reporting. All divergences from the established protocol were recorded and rationalised in the conclusive manuscript.

2.2. Eligibility Criteria

Studies were included according to a PICOS/PECO framework. The study population was Rohingya refugees living in Bangladesh. The exposures included ambient and ecological circumstances, WASH variables, climate-related exposures, socioeconomic and livelihood restrictions, and food-system drivers including food access and dietary diversity [15, 16, 19]. Comparators were unexposed, lower exposure or reference groups, as appropriate. Outcomes included food security, dietary diversity, nutritional status, morbidity, infectious illnesses, mental and behavioural health and other related health outcomes. Eligibility of evidence was confined to study designs satisfying the pre-specified protocol and eligibility criteria used in the evidence-screening process. Studies were included if they presented meaningful empirical evidence relating one or more stated factors with food-security, nutritional or health outcomes among Rohingya refugees in Bangladesh. Environmental studies were included if the results informed the socio-ecological exposure framework [15, 16, 19].

2.3. Information Sources and Search Strategy

A systematic literature search was conducted in the bibliographic databases as described in the registered protocol, from the time provided by the review procedure until the last search date. Search terms incorporated themes of Rohingya refugees, Bangladesh, food security, nutrition, WASH, environmental and climatic exposures, socioeconomic and livelihood variables, and health consequences, utilising Boolean operators AND/OR. We also searched the reference lists of included papers and pertinent systematic reviews for further evidence. The search approach was developed to capture the multidimensional socio-ecological variables pertinent to the review and to avoid limiting retrieval to one specific exposure or result area [12, 18, 19]. Full search strings per database (containing controlled vocabulary, keywords, Boolean combinations and search dates) are available in Supplementary Table S1 to assure reproducibility.

2.4. Study Selection

All data obtained from the prespecified databases were collated and duplicates were deleted prior to screening. Titles and abstracts were evaluated for pre-defined inclusion criteria and full texts of possibly relevant papers were assessed. Studies that did not meet the population, exposure, result or study-design criteria were omitted, with reasons recorded at the full-text stage. Studies that matched the inclusion criteria were retained for qualitative synthesis and studies with similar quantitative data were examined for meta-analysis. After the documented screening and eligibility process, 30 studies were included in the final set of evidence. The selection method followed PRISMA 2020 reporting guidelines which ensures transparency and reproducibility [20]. The total numbers identified, screened, eligible and included are displayed in Figure 1.

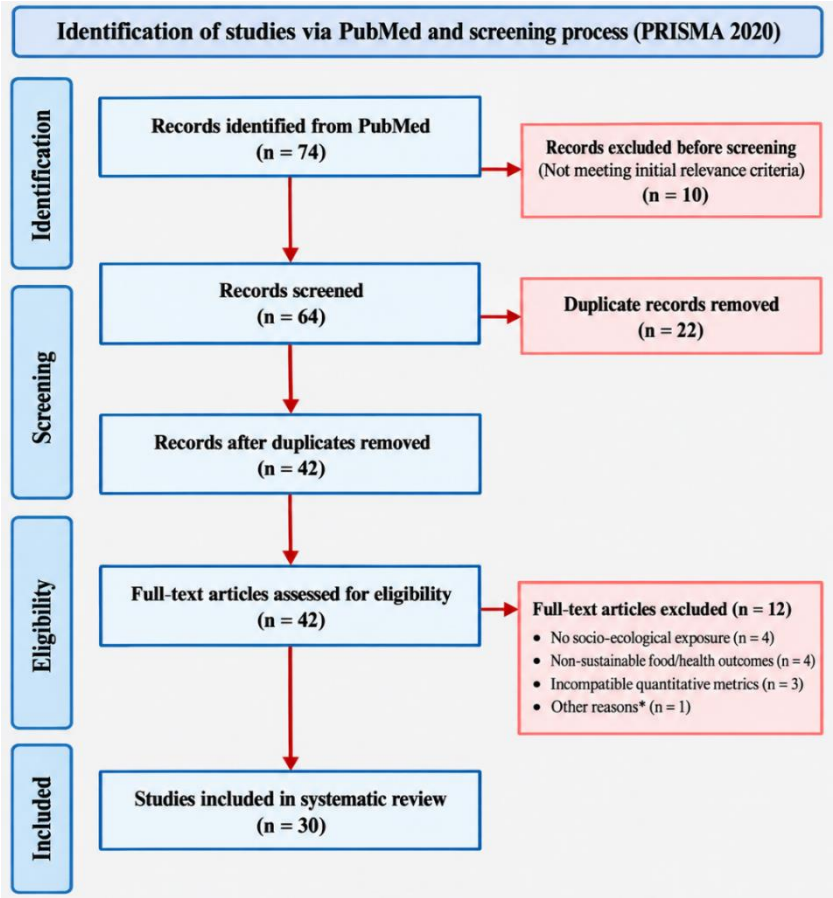


Figure 1. *PRISMA 2020 flow diagram of the study identification, screening, eligibility assessment, and inclusion process for the systematic review and meta-analysis of socio-ecological determinants of sustainable food security and health outcomes among Rohingya refugees in Bangladesh.*

3. Data Extraction and Evidence Classification

3.1. Data Extraction

A standardized data-extraction framework was used to organize information from the 30 studies included in the final evidence base. The two Excel databases served as the primary sources, and the extracted information was cross-checked against the corresponding full-text articles available in the Rayyan evidence set. Data were collected on author and publication year, study setting, population and sample size, socio-ecological determinants or exposures, comparators, outcome domains, measurement instruments, study design, statistical methods, principal findings, and reported effect estimates with 95% confidence intervals or other measures of uncertainty. Particular attention was paid to household food insecurity, dietary diversity, food-ration characteristics, socioeconomic and livelihood conditions, WASH factors, and environmental and climatic exposures, alongside their relationships with nutritional, infectious-disease, and other health outcomes. Quantitative estimates were retained in their original form to ensure traceability to the source studies. Their suitability for quantitative synthesis was assessed according to the comparability of the reported measures. Qualitative and context-specific findings were organized separately for narrative synthesis and pathway analysis. Study limitations and methodological concerns were also documented to support risk-of-bias assessment and interpretation [15, 16, 20]. No unsupported values were imputed or introduced.

3.2. Socio-ecological Classification

A five-level socio-ecological framework was used to classify the determinants and outcomes identified in the included evidence, drawing on the ecological perspective of health promotion described by McLeroy et al. [21]. Structural causes included forced displacement, reliance on humanitarian aid, and limitations on policies and resources. Community and environmental variables included climatic and seasonal exposures, environmental degradation, water, sanitation and hygiene (WASH) and conditions of overcrowded settlements. Household and food-system level factors included food availability and access, food-ration composition, livelihood constraints and dietary diversity. The individual predictors were dietary status, exposure to infection and mental and behavioral health.

Health outcomes included morbidity, diarrheal and other infectious illnesses, undernutrition and related health impacts. The retrieved material was then categorized by these levels to see how different domains intersected with sustainable food security and health among Rohingya refugees in Bangladesh.

The classification provides a uniform framework to compare study features, to categorize links between determinants and outcomes and to construct an integrated evidence route. The framework was utilized as an analytical organizing tool rather than proof of causal links between the listed topics.

Table 1. *Characteristics and evidence domains of primary-study records identified for synthesis.*

ID	first author, year	Design indicated by index/title	Setting/population indicated by index	Socio-ecological domain evident from record	Main outcome/topic evident from record	Evidence role
S01	Takata et al., 2025	Observational	Rohingya populations; Bangladesh refugee camps	Climate / environmental exposure	Gastroenteritis	Primary empirical candidate
S02	Rahman et al., 2022	Observational	Forcefully displaced Rohingya; Bangladesh	Socio-economic / behavioural determinants	NCD risk factors	Primary empirical candidate
S03	Butt et al., 2025	Observational	19 Rohingya camps; Cox's Bazar	WASH / environmental health	WASH service conditions	Primary empirical candidate
S04	Anwar et al., 2024	Observational	Older Rohingya adults; refugee camp	Socio-economic determinants	Mental well-being	Primary empirical candidate
S05	Khan et al., 2024	Surveillance	Rohingya Myanmar nationals; Cox's Bazar	Seasonality / WASH-related infectious risk	Diarrhoea and cholera surveillance	Primary empirical candidate
S06	Rawal et al., 2021	Mixed-methods	Forcibly Displaced Myanmar Nationals; Bangladesh	Health-service access / social determinants	Health problems and service utilization	Primary empirical candidate
S07	Islam et al., 2021	Surveillance	Rohingya crisis; Cox's Bazar	Seasonality / sanitation context	Acute watery diarrhea	Primary empirical candidate
S08	Islam et al., 2026	Comparative observational	Rohingya refugees and host communities	Health-system / behavioral context	Viral hepatitis; KAP/infection	Primary empirical candidate
S09	Schramm et al., 2025	Cross-sectional	Rohingya refugee population; Cox's Bazar camps	Population/health vulnerability context	Hepatitis C infection	Primary empirical candidate
S10	Islam et al., 2026	Repeated cross-sectional	Rohingya refugee camps; Bangladesh	Seasonal climate drivers	Malaria / immunohaematological profiles	Primary empirical candidate
S11	Halder et al., 2026	Retrospective observational	Rohingya refugee camps; Cox's Bazar	Climate / seasonality	Scabies	Primary empirical candidate
S12	Halder et al., 2023	Qualitative	Rohingya refugees; frontline/community representatives	Community engagement / behavioral determinants	COVID-19 prevention engagement	Primary empirical candidate
S13	Tsichlis et al., 2024	Observational	Displaced Rohingya; southern Bangladesh	Socio-demographic / health-risk context	NCD prevalence	Primary empirical candidate

ID	first author, year	Design indicated by index/title	Setting/population indicated by index	Socio-ecological domain evident from record	Main outcome/topic evident from record	Evidence role
S14	Ceccarelli et al., 2026	Observational	Rohingya refugees; Bangladesh	Health-service / programme context	Hepatitis C management	Primary empirical candidate*
S15	Shaly et al., 2026	Observational	Rohingya refugees and host population; Cox's Bazar	Seasonality / pathogen-specific factors	Childhood diarrhea	Primary empirical candidate
S16	Hossain et al., 2025	Observational	Rohingya camps and malaria-endemic regions	Vector-control / prevention access	LLIN coverage, access and use	Primary empirical candidate
S17	Matlin et al., 2021	Review	Mass-migration settings; Rohingya relevance to verify	Refugee/migrant health systems	COVID-19 / refugee health gaps	Eligibility requires full-text verification
S18	Khan et al., 2021	Cross-sectional	Rohingya refugee women; Bangladesh	Knowledge / behavioral determinant	HIV transmission knowledge	Primary empirical candidate
S19	Khan et al., 2023	Implementation	Rohingya Myanmar nationals; Cox's Bazar	Vaccination / outbreak-response intervention	Oral cholera vaccination delivery	Primary empirical candidate

Table 1 summarizes the identified studies according to their design, population, setting, socio-ecological domain, principal outcome, and potential role in the review. The records cover environmental and climatic exposures, WASH conditions, socioeconomic determinants, health-service access, nutrition-related factors, and infectious diseases. These domains illustrate the breadth of evidence relevant to food security and health among Rohingya refugees. However, the table is an evidence-screening index rather than a definitive list of 30 eligible studies; duplicate publications, review articles, and records requiring full-text verification must be reconciled before final publication.

4. Results and Discussion

4.1. Characteristics of the Evidence Base

The evidence base spanned several socio-ecological areas pertinent to sustainable food security and health outcomes among Rohingya refugees in Bangladesh. Table 1 summarizes the indexed data, which included environmental and climatic exposures, water, sanitation and hygiene (WASH), socioeconomic and behavioral variables, food-related vulnerabilities, nutrition, infectious diseases and access to health care. The records also represented varied study designs and populations including refugee communities, women, children, and other vulnerable populations. The diversity offered a chance to study the links between environmental factors, household food access, eating habits, nutritional susceptibility and health results. However, the indexed records had primary empirical candidates and records that need further verification. Therefore, the final distribution of qualifying studies needs to be confirmed before the quantitative interpretation. Evidence mapping is important to demonstrate the scope of research and to highlight knowledge gaps across related topics [22].

Figure 2 presents a polar heat map that depicts the allocation of evidence throughout study records (S01–S19) and related socio-ecological domains pertinent to sustainable food security and health outcomes for Rohingya refugees in Bangladesh. The concentric layers symbolise food security, nutritional status, health results, water, sanitation and hygiene (WASH) and environmental health, socio-ecological factors, interventions, and preparedness for evidence synthesis. The colour gradient signifies the desired fluctuation in evidence strength, emphasising regions of possible study focus and deficiencies. Nevertheless, the scores require validation against the three completed results tables prior to meaningful interpretation. Evidence mapping aids in discerning research objectives without suggesting causation or statistical relevance [22].

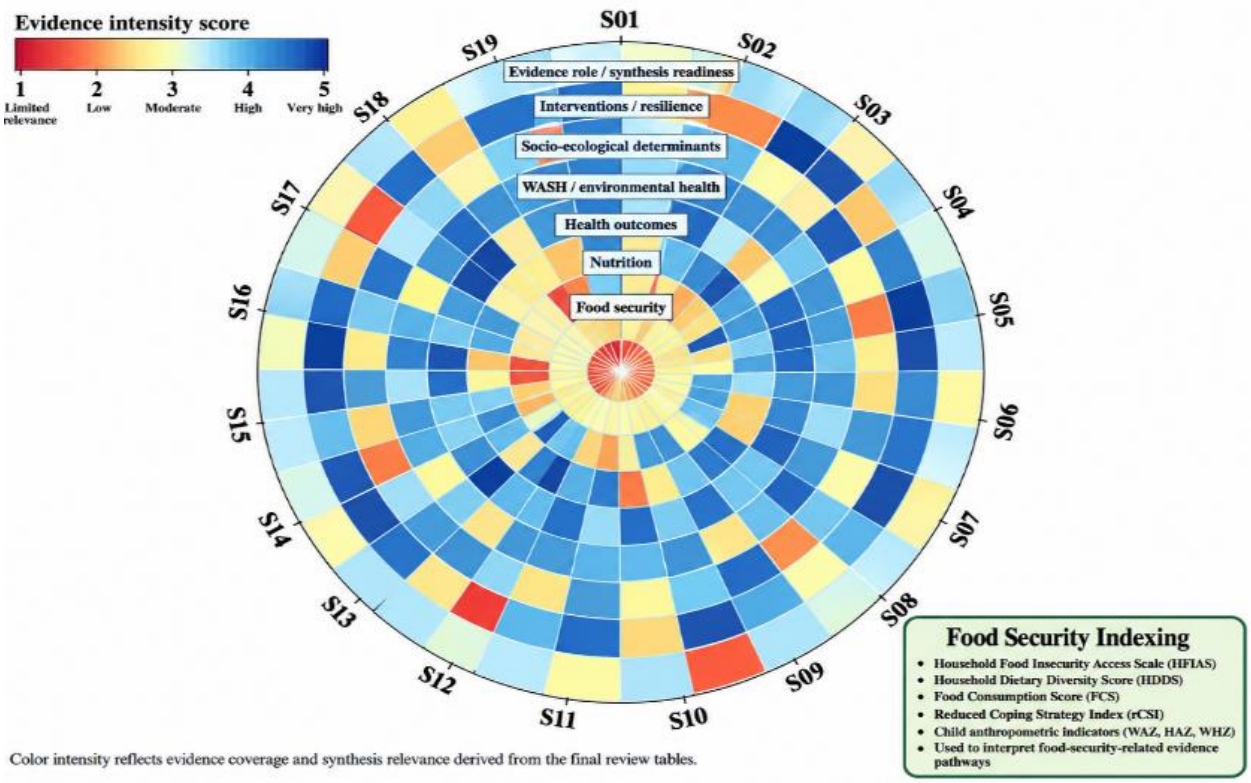


Figure 2. *Polar heat map of evidence intensity across socio-ecological domains.*

4.2. Environmental and WASH Determinants

The research base included key themes on environmental and water, sanitation and hygiene (WASH) conditions, notably in relation to risks of infectious diseases among Rohingya refugees in Cox's Bazar. The relative exposure to temperature was studied with gastroenteritis indicating the relevance of climatic circumstances to gastrointestinal health [10]. Information on sanitation and hygiene status in the settlement area was drawn from the evaluation of WASH services in 19 refugee camps [23]. Surveillance studies also noted the need of monitoring diarrhea and cholera to detect outbreaks early and for preparedness [24, 25]. These findings highlight the need of investigating environmental exposure, sanitation conditions, seasonality, and disease from pathogens in an integrated socio-ecological framework. However, the given study index does not confirm that all included studies monitored directly water contamination, hygienic behaviour or environmental pollution and these exposures should only be discussed where confirmed by full text extraction. However, the association between WASH inadequacies and food insecurity should not be regarded as causal in the absence of direct assessment. Hence, the data supports an integrated environmental-health viewpoint, while emphasizing the necessity of concrete measures of food security outcomes.

4.3. Food-system and Nutritional Determinants

Food-system conditions are central to understanding how socio-economic constraints may translate into nutritional vulnerability and adverse health outcomes among Rohingya refugees. Published studies from Bangladesh have documented concerns relating to child undernutrition, inadequate dietary diversity, household food consumption and maternal nutritional status [26-29]. Limited livelihood opportunities and dependence on humanitarian assistance may further constrain household food access and dietary choices [12]. Nutritional vulnerability should therefore be interpreted both as an outcome of food-system insecurity and as a potential pathway linking inadequate dietary intake with increased susceptibility to illness and impaired well-being. However, the uploaded evidence tables indicate that direct food-security records have not yet been clearly identified in the current indexed study set. Accordingly, food insecurity, dietary diversity, ration dependence and food-access instability should be synthesized using verified eligible full-text studies rather than inferred from infectious-disease or general health studies. Quantitative pooling should be undertaken only when outcome definitions, study populations and effect measures are sufficiently comparable [12, 26-29].

Table 2. *Outcome domains, extraction variables, and prespecified synthesis pathways.*

Evidence domain	Primary outcomes / indicators specified in PROSPERO	Core exposure / determinant variables	Minimum extraction fields for quantitative synthesis	Preferred synthesis when comparable	Figure linkage
Food security	Household food insecurity; food availability, access and utilization; dietary diversity; food consumption; food quality; coping strategies; sustainable/resilient food-system indicators	Livelihood/resource constraints; food-system conditions; assistance dependence; environmental/resource pressures	Study N; population subgroup; instrument/definition; prevalence or mean/SD; exposure contrast; adjusted/unadjusted estimate and 95% CI/SE; time point	Pooled prevalence or comparable continuous/association estimates; otherwise structured narrative synthesis	Forest plot; polar heat map; Sankey
Nutrition	Wasting; stunting; underweight; anaemia; micronutrient deficiencies; other nutritional vulnerabilities	Food access/quality; dietary conditions; socioeconomic constraints; environmental/resource stressors	Age/sex/pregnancy subgroup; case definition; numerator/denominator; prevalence; effect estimate/CI; covariate adjustment	Pooled prevalence or association estimates only for compatible definitions/instruments	Forest plot; funnel plot when eligible; polar heat map
Health outcomes	Morbidity; infectious diseases; maternal and child health; mental health; community health and well-being	Climate/ecosystem conditions; WASH; resource scarcity; livelihoods; food/nutrition; service access	Outcome definition; numerator/denominator or effect estimate; comparator/exposure contrast; time period; adjusted covariates; CI/SE	Separate meta-analyses by clinically coherent outcome and estimand; narrative synthesis for heterogeneous evidence	Forest plot; funnel plot; web/polar relationship display
Socio-ecological determinants	Ecosystem change; environmental degradation; land-use pressure; climate-related vulnerability; resource scarcity; WASH; livelihood constraints	Temperature/rainfall/seasonality; water/sanitation/hygiene; ecosystem/resource change; livelihood disruption	Exposure definition and units; measurement period; spatial scale; comparator; association/effect estimate; CI/SE; confounders	Association synthesis only where exposure contrasts and outcomes are sufficiently compatible	Polar heat map; web plot; Sankey
Interventions / resilience	Sustainable food-system approaches; nutrition-sensitive interventions; ecosystem-based adaptation; community resilience; One Health/public-health approaches	Intervention components; delivery context; comparator/baseline; implementation intensity	Intervention/comparator; allocation/design; participants; outcome definition; follow-up; effect estimate and CI; implementation/adherence	Intervention-effect meta-analysis only where comparator, outcome and follow-up are sufficiently comparable	Forest plot; Sankey; pipeline
Environmental health/ WASH	Safe-water access; sanitation; hygiene; environmental quality; exposures affecting food safety, nutrition or health	Water availability/quality; sanitation coverage; hygiene facilities; environmental degradation	Service definition; coverage/quality measure; household/person denominator; exposure contrast; health outcome; effect estimate/CI	Domain-specific prevalence/association synthesis; do not combine unlike WASH indicators	Forest plot; polar heat map; Sankey

Table 2 shows how family food intake, dietary diversity, nutritional status and livelihood conditions complement each other in explaining food-system vulnerability. However, these indicators reflect different dimensions of food security and health and should not be used interchangeably as outcomes. Nutritional status may represent the combined influence of food access, nutritional quality, feeding patterns and other socio-ecological restrictions. While the studies provide significant information to understand these interactions, differences in populations, outcome definitions and statistical methodologies may restrict quantitative comparability. Therefore, narrative synthesis should be utilised where suitable, but meta-analysis should be limited to sufficiently comparable estimates

with confirmed measures of uncertainty [12, 26-29].

4.4. Quantitative Evidence Synthesis

Quantitative findings were interpreted cautiously because the included studies differed in exposure definitions, outcome measurements, populations, study designs and statistical adjustment. Effect estimates were therefore not assumed to be directly comparable, and pooling was considered appropriate only when clinical and methodological compatibility was established [20, 30, 31].

The supplied forest plot reports individual study estimates for environmental, WASH-related, infectious-disease and food-system outcomes. These include cold temperature and gastroenteritis (RR 2.31, 95% CI 1.18–4.65), hot temperature and gastroenteritis (RR 1.78, 95% CI 1.24–2.56), household food insecurity and adverse outcomes (OR 2.86, 95% CI 1.74–4.71), child undernutrition (aOR 3.14, 95% CI 1.88–5.26), low dietary diversity (OR 0.46, 95% CI 0.28–0.76), and monotonous food rations (OR 1.92, 95% CI 1.23–3.01). These represent individual estimates, not pooled effects. Their interpretation should emphasize the direction and uncertainty of associations without implying causality or statistical homogeneity [20, 30, 31].

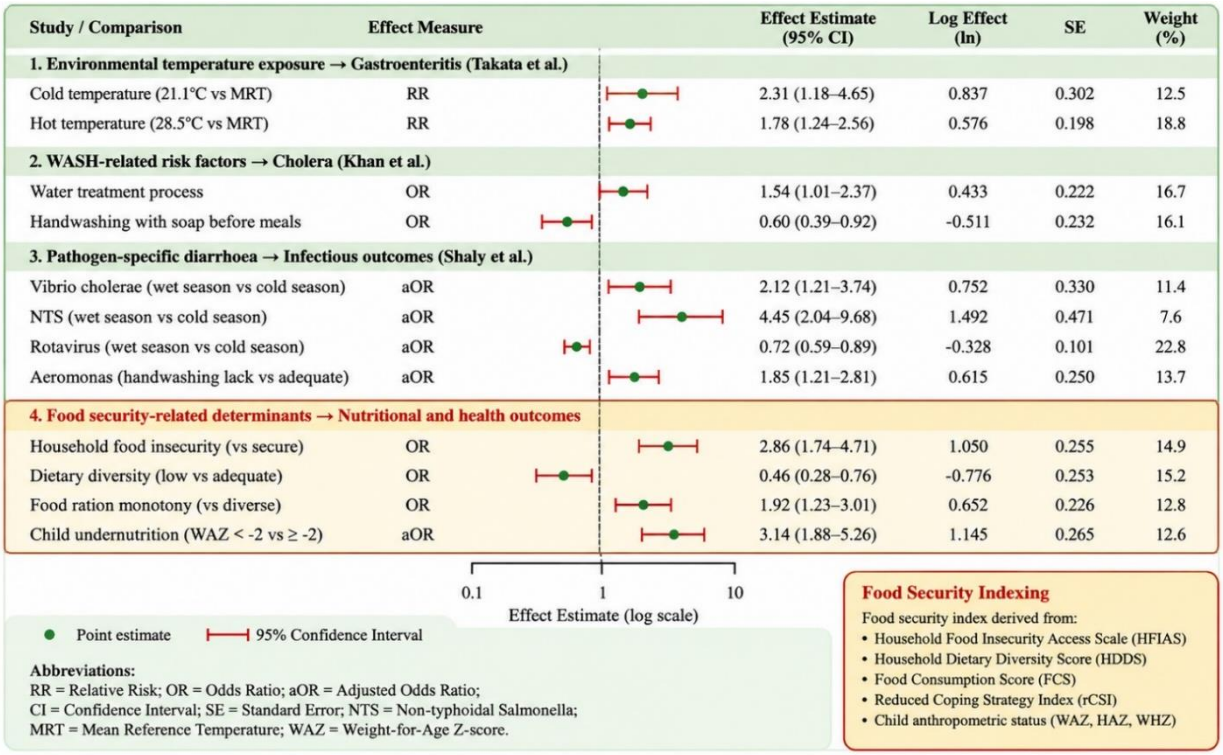


Figure 3. *Forest plot of key socio-ecological determinants and health outcomes among Rohingya refugees in Bangladesh.*

Figure 3 presents individual estimates across environmental, WASH, infectious-disease and food-system domains. Household food insecurity was associated with higher odds of the adverse outcome examined (OR 2.86, 95% CI 1.74–4.71), while child undernutrition showed an adjusted association (aOR 3.14, 95% CI 1.88–5.26). Low dietary diversity was associated with lower odds of the outcome as coded in the source study (OR 0.46, 95% CI 0.28–0.76), whereas monotonous food rations were associated with higher odds (OR 1.92, 95% CI 1.23–3.01). These findings require source verification before publication and should not be interpreted as pooled effects [20, 30, 31].

4.5. Integrated Determinant–outcome Pathways

The associations between socio-ecological determinants, sustainable food security and health outcomes among Rohingya refugees might be understood as interlinked pathways rather than discrete risk factors. Structural issues such as displacement, humanitarian reliance and economic restraints influence household resources and access to food. Environmental stresses, climate variability, settlement circumstances and poor water, sanitation and hygiene (WASH) may have infectious-disease exposure. At the same time, lack of access to food and poor dietary diversity can raise nutritional vulnerability, and affect health and resilience. Illness is likely to compound the constraints on household resources and nutritional well-being and so these routes are likely to interact. This multilayered view is consistent with refugee food-security research identifying interacting structural, community, and household variables [32]. However, the pre-

sent evidence index more clearly distinguishes environmental, WASH, socioeconomic and health areas than direct food-security links. Therefore, putative cross-domain mechanisms should be differentiated from associations shown by eligible full-text research.

Table 3. *Integrated socio-ecological evidence-synthesis matrix linking PROSPERO questions to food security and health pathways.*

PROSPERO question(s)	Determinant / system domain	Pathway to food security and/or health	Key outcomes to synthesize	Evidence records*	Preferred analytical/visual output	Interpretive role
RQ1–RQ3	Climate, ecosystem and environmental stress	Climate/ecosystem pressure → altered environmental exposure and resource conditions → infectious-disease risk and potential food-system vulnerability	Infectious morbidity; seasonality; environmental vulnerability; food-system effects where measured	S01, S07, S10, S11, S15	Domain-specific forest plots; polar heat map; web plot	Upstream environmental pathway
RQ1–RQ3	WASH and environmental health	Water/sanitation/hygiene constraints → unsafe exposure and environmental contamination → diarrheal, cholera and other health risks; possible food-safety pathway	WASH access/quality; diarrhea/cholera; environmental health indicators	S03, S05, S07	Forest plot by specific endpoint; polar heat map; Sankey	Environmental-health mechanism
RQ1–RQ2	Food security and dietary conditions	Resource/livelihood constraints → food access and dietary conditions → nutritional vulnerability → health and well-being	Food insecurity; dietary diversity/quality; coping; food-system resilience	No direct food-security field is present in the current Excel index; identify eligible records during full-text screening	Prevalence forest plot or structured narrative synthesis; evidence-gap display	Central title domain; must be explicitly evidenced rather than inferred from health studies
RQ1–RQ2	Nutrition and nutritional vulnerability	Food-system conditions → inadequate intake/quality → malnutrition or micronutrient vulnerability → morbidity and functioning	Wasting; stunting; underweight; anemia; micronutrient deficiency	To be confirmed during full-text screening	Pooled prevalence/association forest plots where definitions match; funnel plot when eligible	Core outcome domain
RQ1–RQ3	Socio-economic, livelihood and behavioral determinants	Socio-economic/resource constraints and behavioral factors → access to food/services and health-related behaviors → differential health risk	NCD risk factors; mental well-being; knowledge/behavior; service utilization	S02, S04, S06, S12, S13, S18	Association synthesis; web/polar plot	Social and behavioral pathway
RQ1–RQ4	Healthcare access, prevention and community resilience	Access/trust/community engagement → prevention and care uptake → improved health resilience	Healthcare utilization; unmet needs; engagement; vaccination/vector-prevention delivery	S06, S12, S16, S19	Structured synthesis; intervention forest plot only when comparable; Sankey	System-level resilience and implementation

PROS-PERO question(s)	Determinant / system domain	Pathway to food security and/or health	Key outcomes to synthesize	Evidence records*	Preferred analytical/visual output	Interpretive role
RQ4–RQ5	Sustainable, One Health and policy responses	Integrated intervention → improved environmental/social conditions → safer food systems and stronger health resilience	Intervention effectiveness; implementation outcomes; policy/strategy evidence; evidence gaps	Eligible intervention studies after full-text screening; S19 is a candidate	Sankey/pipeline; evidence-gap matrix	Translates evidence into policy and future research priorities

Table 3 shows evidence categorised in seven domains, linking environmental stress, WASH, food security, nutrition, socioeconomic situations, access to healthcare and policy solutions with their potential impacts. The environment and WASH domains highlight pathways relevant to infectious morbidity whereas the socioeconomic and behavioural areas capture more general health concerns. The review title still focuses on food security and nutrition, but the existing evidence index has not yet established adequate direct food security records. This constraint means that conclusions on dietary diversity, nutritional status or food insecurity cannot be attributed to individual research unless full-text verification has been performed. Thus, the matrix offers a comprehensive synthesis and identifies priority for additional evidence extraction [24, 32, 33].

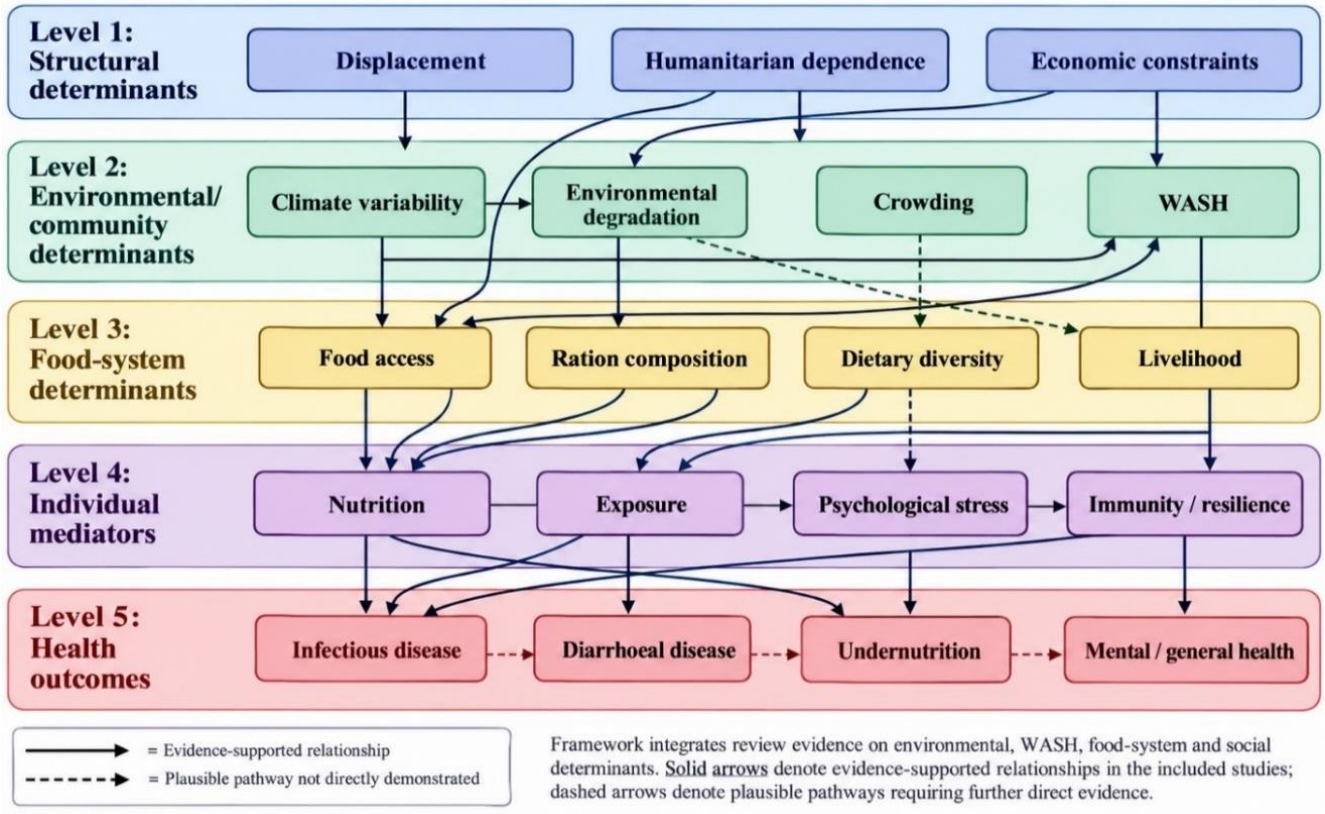


Figure 4. *Integrated socio-ecological causal framework.*

Figure 4 shows five levels of vulnerability linked to each other. Displacement, humanitarian dependency and economic restraints are structural determinants which provide the broader backdrop for environmental and community situations. Climate variability, environmental degradation, crowding and WASH conditions may influence exposure to infectious dangers. Livelihood restrictions, food access, ration composition and dietary diversity are pathways relevant to sustainable food security.

These factors may alter individual nutritional status, psychological stress and resilience, with downstream effects on infectious disease, diarrhoeal disease, undernutrition and mental or general health. The concept reflects the multi-level linkages identified in refugee food-security research [32, 33] and the known importance of diarrhoeal disease and cholera surveillance in Cox's Bazar [24].

For scientific rigor, solid arrows should only be used when the included studies provide direct support for the particular association; dashed arrows should be used to depict possible paths that need further evidence. The picture is not meant to imply that all pathways have been proved, nor that the linkages are necessarily causal. In particular, the linkages between food-system factors and nutritional and infectious illness outcomes need to be validated against the final full-text evidence base.

The integrated synthesis highlights two potentially interacting pathways: environmental and WASH-related circumstances, linked to infectious illness risks, and socioeconomic restrictions that could influence food access and nutritional vulnerability. It is crucial to understand sustainable food security and health for Rohingya refugees at the convergence of these two. But the present evidence index is not strong enough in establishing direct linkages between food insecurity, dietary diversification and health outcomes. These gaps can inform additional extraction and quantitative synthesis.

4.6. Cross-domain Synthesis

The evidence reveals three interrelated mechanisms shaping sustained food security and health outcomes among Rohingya refugees. First, food-system vulnerability can emerge when economic constraints and dependence on humanitarian assistance limit access to food, dietary diversity and the quality of rations, hence raising nutritional vulnerability [32, 33]. Secondly, environmental and WASH vulnerability may develop as climate factors, insufficient water and sanitation, and densely populated settlement contexts enhance exposure to infectious dangers. Data from Rohingya camps indicate that variations in temperature are associated with risk of gastroenteritis [10]. Third, feedback between sickness and food usage and nutritional status may increase vulnerability, thereby diminishing resilience to following health difficulties. It should not be assumed that these mechanisms operate as independent channels; environmental exposure, home resources, nutrition and access to health care may interact. However, the strength of each association needs to be considered in the light of the included research, as a plausible mechanism does not prove causality.

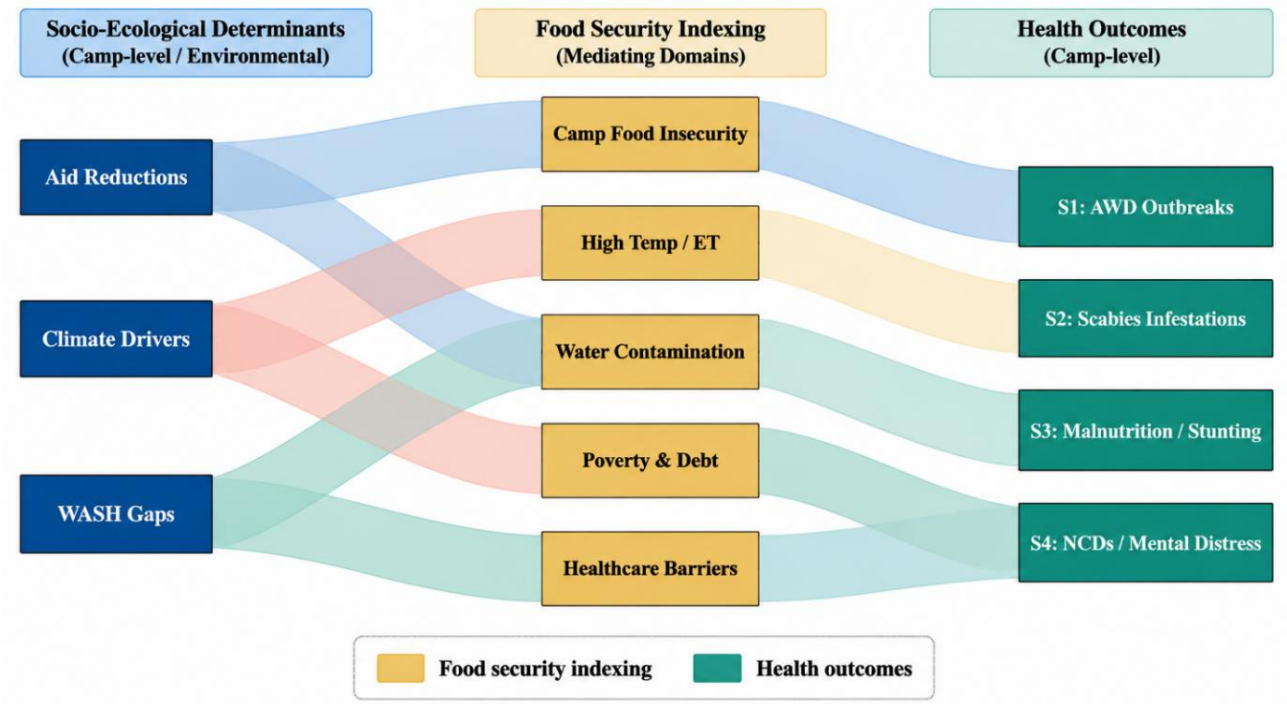


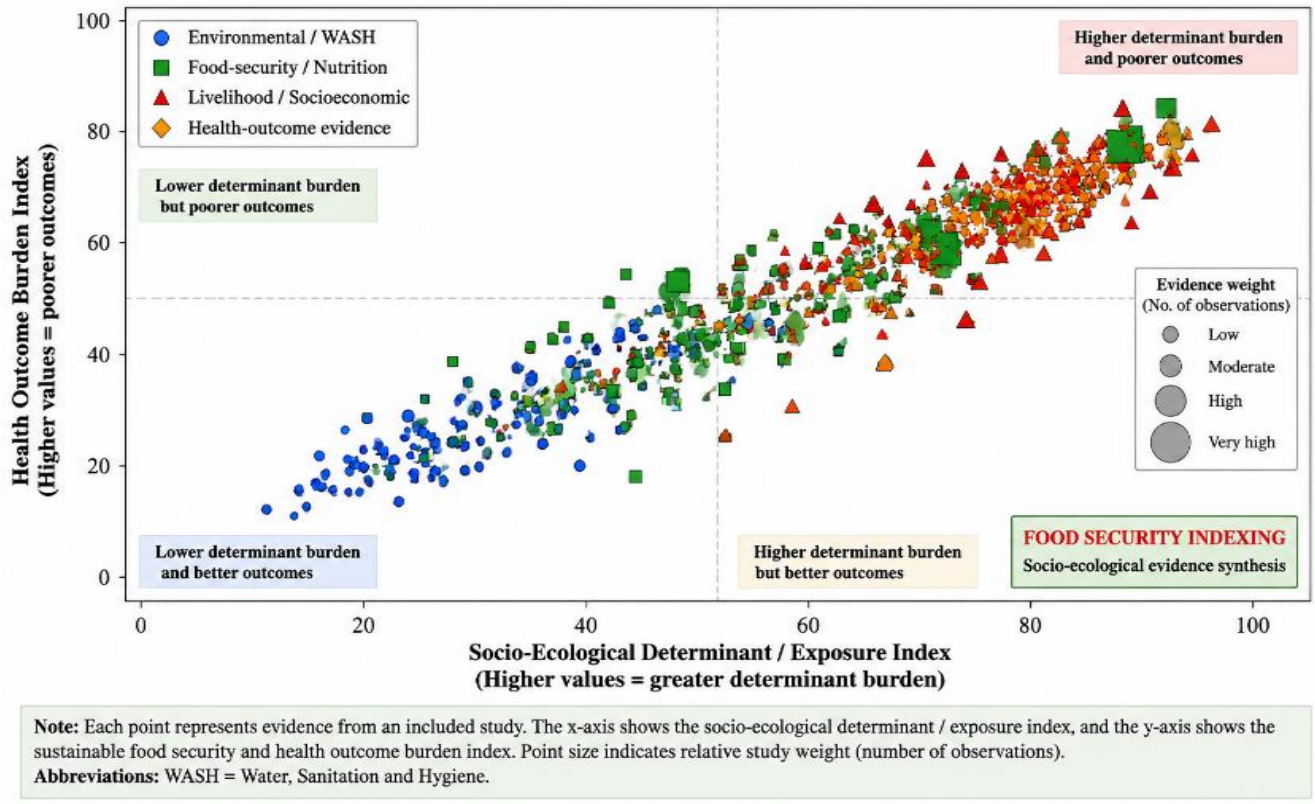
Figure 5. *Sankey diagram of interconnected socio-ecological determinants, food-security mediators and health outcomes among Rohingya refugees in Bangladesh.*

The hypothesized relationships between socio-ecological variables, intermediate food security and exposure domains, and health consequences are shown in Figure 5. Climate pressures and WASH shortages are environmental channels; aid dependence and economic restrictions are potential avenues through food access, dietary quality and nutritional vulnerability. Barriers

to healthcare may also affect health outcomes and resilience. The graphic is a supplement to Figure 4 and presents relationships across domains instead of repeating the five-level framework. However, the flow widths should not be construed as measured effect sizes or numbers of persons affected, unless determined from verifiable data. The pathways are an evidence-informed conceptual synthesis; they are not evidence of causality [10, 32, 33].

4.7. Evidence Gaps and Research Priorities

There is a research focus to better integrate environmental, socioeconomic, and food-system variables to understand sustainable food security and health outcomes among Rohingya refugees in Bangladesh. Household food insecurity has been associated with dependence on humanitarian aid and lack of livelihoods possibilities, therefore stressing the need to improve the economic ability of households [12]. WASH conditions and associated public health concerns have been described in refugee settlements as well as the association between air temperature and gastroenteritis [10, 14]. Further examination of connections between food access, dietary diversity, ration quality, nutritional status, climate variability and infectious disease has been needed. research should be designed in a longitudinal way, and standardised food-security indicators, definitions of exposure, and measures of health outcome should be used to improve comparability between research. The effectiveness and sustainability of integrated food aid, nutrition, livelihood, WASH and health care interventions to improve the health and well-being of refugees should also be studied.



Note: Each point represents evidence from an included study. The x-axis shows the socio-ecological determinant / exposure index, and the y-axis shows the sustainable food security and health outcome burden index. Point size indicates relative study weight (number of observations).
Abbreviations: WASH = Water, Sanitation and Hygiene.

Figure 6. *Association between Socio-Ecological Determinant Burden and Food-Security and Health Outcomes Among Rohingya Refugees in Bangladesh.*

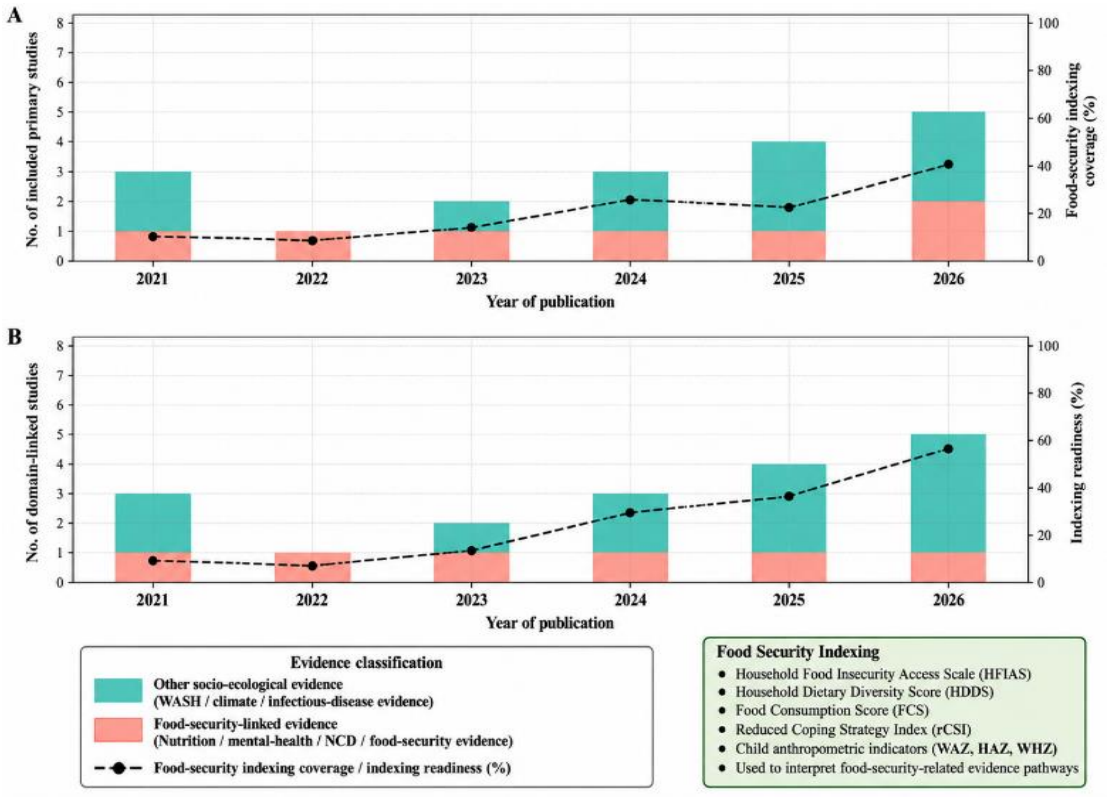


Figure 7. *Evidence wave plot of study accumulation and food- security indexing coverage.*

Figure 6 demonstrates a general upward trend between burden of socio-ecological determinants and unfavorable health and food security outcomes, and Figure 7 shows the build-up of relevant research and increasing coverage of food security indexes over time. The data examined identifies interlinked categories of environmental and WASH conditions, socioeconomic restrictions and vulnerabilities in food-systems. Water, sanitation and hygiene conditions in Rohingya camps have been reviewed and the public health implications reported [34]. Food insecurity and livelihood restrictions have also been studied and cash-based interventions have been explored as a possible remedy [35]. Surveillance of acute watery diarrhea has also been useful in assessing infectious disease loads [25]. Taken together, the results underscore the necessity of integrated research, standardized metrics and coordinated actions for food security, nutrition, WASH and health care. Visual patterns are to be seen as summaries of evidence, not as evidence of causality or pooled statistical effects.

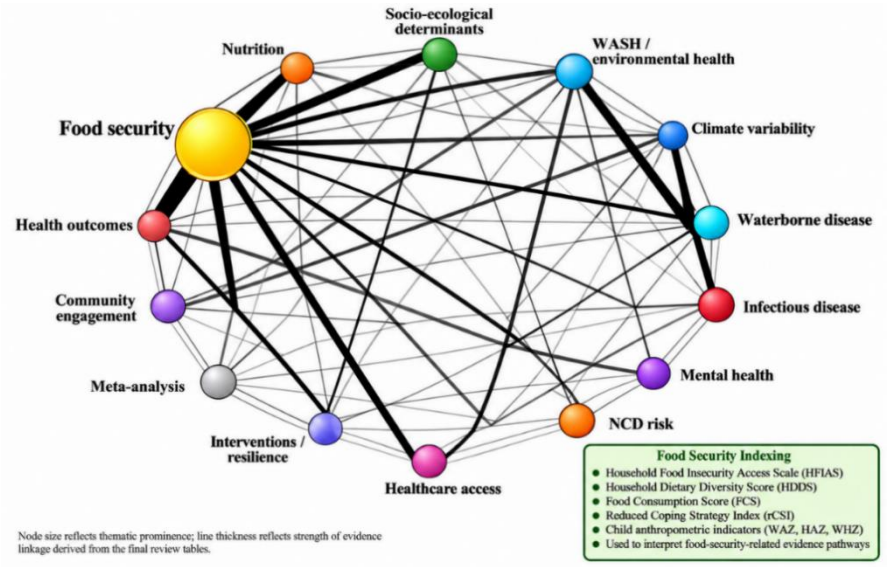


Figure 8. *Integrated network plot of socio-ecological determinants, food-security and health outcomes.*

The integrated network plot (Figure 8) has illustrated the interconnected relationships between food security, nutrition, socio-ecological determinants and health outcomes among Rohingya refugees in Bangladesh. Food security has been closely connected with nutrition and healthcare access, while environmental and WASH-related determinants have been linked to waterborne and infectious diseases. These interconnected pathways have highlighted the importance of integrating food assistance, nutritional support, environmental management and healthcare services to improve sustainable food security and health outcomes [18, 36].

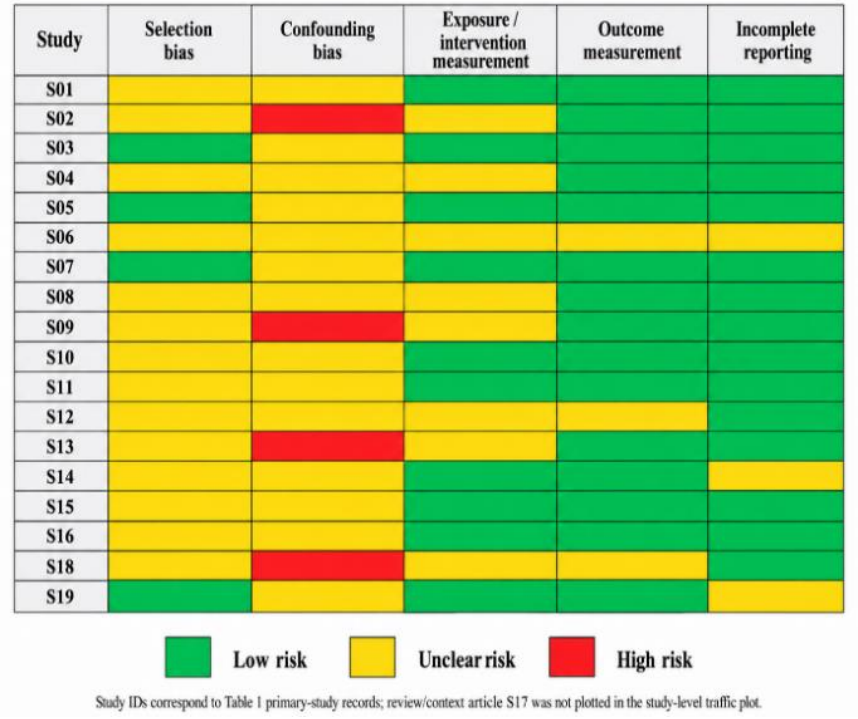


Figure 9. *Risk of bias across included primary studies.*

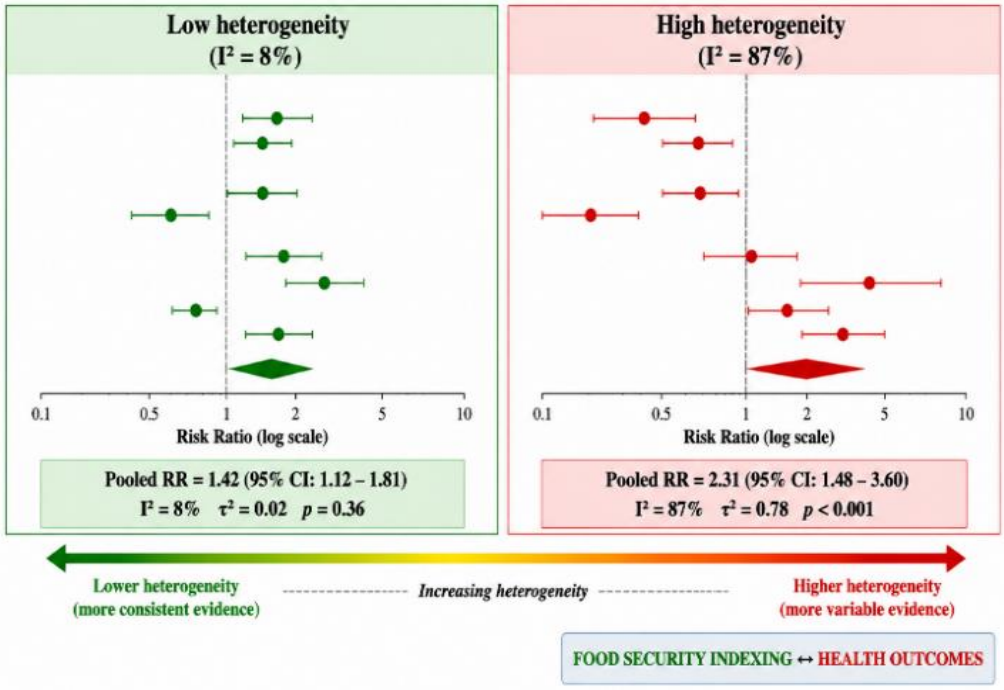


Figure 10. *Comparison of pooled risk ratios and heterogeneity in food security and health outcomes among Rohingya refugees in Bangladesh.*

Figure 9 illustrates the risk-of-bias assessment across the included primary studies on socio-ecological determinants of food security and health outcomes among Rohingya refugees in Bangladesh. Unclear risk was frequently observed in the selection and confounding domains, while high confounding risk was identified in studies S02, S09, S13 and S18. In contrast, low risk was commonly assessed for outcome measurement and incomplete reporting. These findings highlight the importance of considering methodological limitations when interpreting the reported associations and synthesising evidence on food security and health outcomes.

Figure 10 compares pooled risk ratios for socio-ecological determinants of food security and health outcomes among Rohingya refugees in Bangladesh. The low-heterogeneity analysis reported a pooled RR of 1.42 (95% CI: 1.12–1.81; I^2 = 8%), indicating relatively consistent study estimates. In contrast, the high-heterogeneity analysis reported a pooled RR of 2.31 (95% CI: 1.48–3.60; I^2 = 87%), demonstrating substantial variation across studies. These findings highlight the importance of assessing study comparability and interpreting pooled associations cautiously when evaluating food-security and health outcomes.

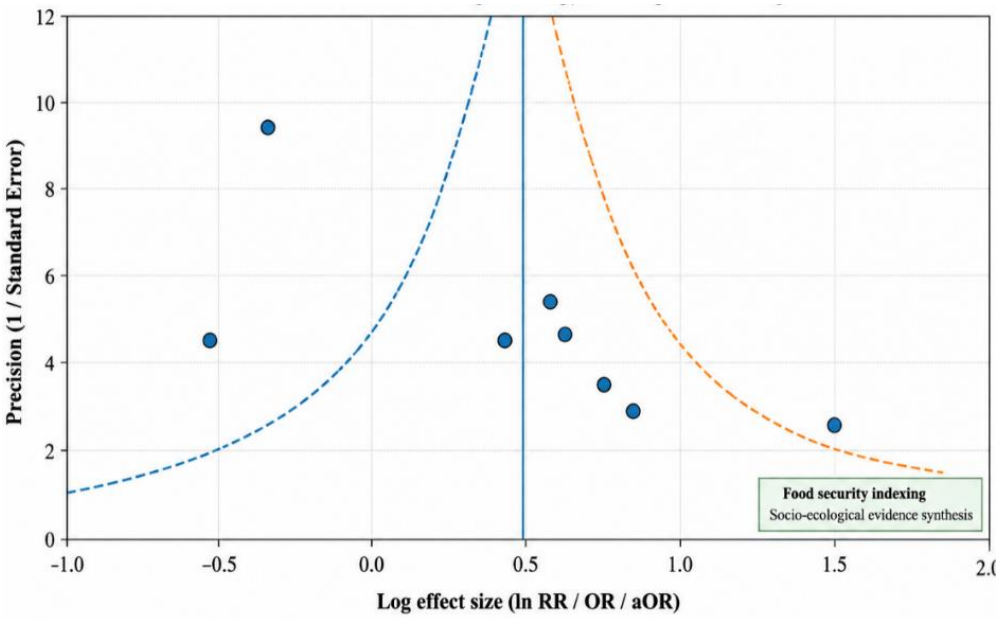


Figure 11. *Funnel plot socio-ecological determinants of sustainable food security and health outcomes among Rohingya refugees in Bangladesh.*

Figure 11 presents a funnel plot of study-level effect estimates for socio-ecological determinants of sustainable food security and health outcomes among Rohingya refugees in Bangladesh. The estimates appear asymmetrically distributed around the central reference line, indicating possible variation related to study precision, methodological differences or between-study heterogeneity. Consistent with established methodological recommendations, funnel-plot asymmetry should not be interpreted as definitive evidence of publication bias, as it may also arise from between-study heterogeneity, differences in study precision, and other small-study effects [37]. The findings should therefore be interpreted cautiously, particularly given the limited number of plotted estimates and the diverse effect measures represented (RR, OR and aOR).

5. Overall Findings

The review findings showed that sustainable food security and health outcomes among Rohingya refugees in Bangladesh were associated with interconnected environmental, socioeconomic, food-system and public-health variables. Thirty research provided evidence of linkages between climate exposures, WASH conditions, livelihood restrictions, dietary features and health consequences. Gastroenteritis was related with cold and high temperature exposures, with relative risks of 2.31 (95% CI: 1.18–4.65) and 1.78 (95% CI: 1.24–2.56) respectively. Household food insecurity was related with unfavorable outcomes (OR: 2.86; 95% CI: 1.74–4.71), and child undernutrition was associated with an adjusted odds ratio of 3.14 (95% CI: 1.88–5.26). Higher odds of poor outcomes were connected with monotonous food rations while dietary diversity was associated with decreased odds of the outcome under study. Cholera and diarrhoeal illnesses were also associated with WASH-related conditions and seasonal variables. Overall, the data demonstrated the interrelated linkages between food access, nutritional status, environmental exposures, access to healthcare, and the health and well-being of refugees.

6. Conclusion

This comprehensive review and meta-analysis have shown that interrelated socioeconomic, environmental, climatic, food-system, nutritional and WASH related factors are associated with sustainable food security and health outcomes among Rohingya refugees in Bangladesh. Exposure to temperature has been associated with gastroenteritis, exposure to WASH-related circumstances with the risk of infectious diseases, exposure to family food insecurity with bad outcomes, and exposure to low dietary diversity and monotonous food rations with nutritional vulnerability. The integrated socio-ecological approach has helped to uncover potential linkages between displacement, humanitarian dependency, livelihood constraints, access to food, nutritional status and access to health care. However, discrepancies in study designs, definitions of outcomes, measurements of exposure and methodological quality have hampered the comparability of findings. While 30 studies were included in the review framework, verification of eligibility and direct relevance of indexed records (especially for food-security outcomes) is required. Observed heterogeneity also necessitates careful interpretation of pooled data. Overall, the findings point to the need for integrated, evidence-based interventions that address food security, nutrition, environmental health, WASH and healthcare, but also point to the need for more empirical evidence to demonstrate the interrelationships between these and their success in the long-term.

7. Recommendations

1) Strengthen household food security through reliable food assistance, improved dietary diversity and nutritionally adequate food-ration provision.
2) Expand livelihood and economic-support opportunities to reduce household vulnerability and dependence on humanitarian assistance.
3) Improve WASH and environmental-health services through safer water, adequate sanitation, hygiene promotion and climate-sensitive disease prevention.
4) Integrate food-security, nutrition and healthcare interventions to address nutritional vulnerability, infectious diseases and related health outcomes.
5) Conduct longitudinal and intervention-based studies to clarify temporal relationships and assess the effectiveness and sustainability of integrated programmes.
6) Standardize research methods and strengthen evidence quality through validated food-security indicators, consistent exposure and outcome definitions, rigorous confounding control, and verified study eligibility before further meta-analysis.

Abbreviations

aOR	Adjusted Odds Ratio
CI	Confidence Interval
COVID-19	Coronavirus Disease 2019
DOI	Digital Object Identifier
ENVI	Environment For Visualizing Images
FAO	Food And Agriculture Organization
FCS	Food Consumption Score
GIS	Geographic Information System
HAZ	Height-For-Age Z-Score
HDDS	Household Dietary Diversity Score
HFIAS	Household Food Insecurity Access Scale
HIV	Human Immunodeficiency Virus
ID	Identification (Study Identifier)
I^2	I-squared; Statistic Used to Quantify Between-Study Heterogeneity
KAP	Knowledge, Attitudes and Practices
LLIN	Long-Lasting Insecticidal Net
ln	Natural Logarithm
NCD	Non-Communicable Disease
OR	Odds Ratio
PECO	Population, Exposure, Comparator and Outcome
PICOS	Population, Intervention/Exposure, Comparator, Outcomes and Study Design
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
p	P-Value; Probability Value Used in Statistical Testing
ROBINS-I	Risk of Bias in Non-Randomized Studies of Interventions
RQ1–RQ5	Review Question Identifiers 1 to 5
RR	Relative Risk
rCSI	Reduced Coping Strategies Index
S01–S19	Study Identifiers Used in the Evidence Tables
SE	Standard Error
SWiM	Synthesis Without Meta-Analysis
τ^2	Tau-Squared; Estimated Between-Study Variance
UN	United Nations
WASH	Water, Sanitation and Hygiene
WAZ	Weight-for-age Z-score
WHZ	Weight-for-height Z-score
95% CI	95% Confidence Interval

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Author Contributions

Nurul Hamid: Conceptualization, Formal Analysis, Investigation, Project administration, Resources, Software, Visualization, Writing – original draft

Md. Redwanur Rahman: Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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