



Climate, Nutrition and Community Health Developing a Holistic Resilience Framework for Vulnerable Rural Populations

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Abstract— Ecosystems, nutrition, and community health are becoming more interdependent, with vulnerable rural populations being disproportionately impacted by complex environmental, socioeconomic and biological pathways. This study brings together the latest evidence to explore the impact of climate change on agricultural production, food systems, nutrition security, water resources and physical and mental health and considers the multi-dimensionality of rural vulnerability. The study critically analyses the effects of climate variability, extreme weather events, ecosystem degradation and socioeconomic inequalities on food availability, dietary diversity, disease burden and access to health care services. It also reviews the potential for resilience-building measures such as climate-smart agriculture, nutrition-sensitive measures, resilient health-care systems, sustainable water and sanitation management, ecosystem conservation, community engagement and inclusive governance. The study suggests a climate-nutrition-health resilience framework for enhancing the resilience of households and communities, based on recent advances in resilience science, which encompasses the intersection of environmental sustainability, food security, healthcare preparedness, institutional coordination, and local knowledge. The framework focuses on quantifiable measures of resilience to help guide evidence-based planning, policy integration, and ongoing tracking of rural outcomes. The study also pinpoints significant implementation issues due to financial constraints, institutional capacity, technological gaps and social inequities, and proposes priorities for future interdisciplinary research. Overall, the study provides a solid conceptual basis for policymakers, researchers, and development practitioners to increase the resilience of rural communities in the face of growing climate uncertainty, based on coordinated multisectoral approaches that integrate climate adaptation, nutrition, community health and environmental stewardship.

Keywords: Climate change; Community health; Nutrition security; Rural resilience; Sustainable food systems

1. INTRODUCTION

Climate change is one of the major challenges that poses threats to human health, environmental sustainability and socioeconomic development, especially in rural areas where livelihoods are highly dependent on nature. Agriculture, livestock, fisheries and the ecological services of rural populations are pillars of livelihoods and sources of food, nutrition and health security, particularly for rural communities, making them vulnerable to climatic disturbances. The rise in temperatures, erratic rainfall, extended droughts, flooding and degradation of land systems are causing food production systems to be affected and are also putting additional stress on already vulnerable health and nutrition systems. The potential of sustainable agricultural technologies, such as bio-based nanofertilizers, in enhancing productivity while mitigating environmental impacts, further underscores the need for innovative solutions to address the vulnerabilities of rural populations in a resilient manner (Arora et al., 2024).

No two communities are equally vulnerable to the impacts of climate change, which are determined by socioeconomic conditions, environmental exposure, institutional capacity and access to resources. Rural households have a lower level of adaptive capacity, as they are relying on climate-sensitive livelihoods; they have weak infrastructure and limited access to health services; and they continue to suffer from poverty. Climatic shocks often exacerbate social and economic vulnerabilities and stresses that lead to food insecurity, income instability, and health risks. A review of vulnerability across semi-arid regions shows that there are significant differences in vulnerability among households, depending on livelihood diversity, access to natural resources, level of education, and institutional support,



highlighting that there are no one-size-fits-all solutions for resilience strategies (Segnon et al., 2021). Building resilience thus needs to be based on policies that link climatic hazards and structural factors that affect rural vulnerability. Climate change, nutrition and community health are intricately linked by various biological, environmental, and socio-economic pathways. Lower yields in agriculture impact food availability and dietary diversity; lower food quality leads to undernutrition, micronutrient deficiencies and an increasing burden of undernutrition alongside overweight and obesity. This nutritional shift is a complicated double burden of malnutrition that is mainly affecting vulnerable people under the environmental and economic pressures (Popkin et al., 2020). At the same time, food safety has become a big concern due to the risk of climatic changes affecting the pattern of pesticide use, and resulting in the longer lifespan of pesticide residues in food products, underscoring the need for efficient monitoring systems to ensure food safety for people (Wahab et al., 2022). Climate-related disasters not only create physical health challenges, but also psychological distress, anxiety and long-term mental health impacts as well, meaning community resilience needs to be holistic and include both physical and mental health beyond disease prevention (Béné et al., 2021; Hayes & Poland, 2018). The challenge of agriculture, nutrition, water management and health is often tackled as separate domains. The holistic resilience approach acknowledges that a sustainable betterment of rural wellbeing only be achieved through a coordinated and integrated approach to the food system, environmental management, healthcare, governance and community engagement. This approach enhances adaptive capacity and preparedness to future climatic shocks. New resilience-based strategies highlight food systems as a network of local and global food systems that respond to environmental, economic, social shocks and stresses by working together, diversifying, and using sustainable resource practices (Wood et al., 2023). In addition, technological advancements in water processing and resource management, such as nanotechnology-based water purification systems, present potential solutions for better water quality and availability vital factors for public health and climate-smart rural development (Jackson et al., 2025). This study is designed to integrate findings from the linkages between climate change, nutrition and community health to create a climate change community resilience framework for vulnerable rural populations. It analyses the effects of climate change on food systems, nutrition and water resources, as well as integrated solutions to enhance the adaptation of households and communities. A focus on sustainable agriculture, resilient food systems, healthcare preparedness and community-based governance. The COVID-19 pandemic has underscored the importance of coordinated responses to safeguard food security, nutrition and health in the context of multiple crises.

2. Conceptual Foundations of Rural Resilience

2.1 Definition and Dimensions of Resilience

Rural resilience is the ability of people, families, communities and institutions to prepare for, withstand, adapt to and bounce back from environmental, economic and social shocks and stresses and to sustain critical functions and foster sustainable development. Resilience is not a single attribute, but ecological integrity, economic stability, social cohesion, institutional effectiveness, and public health preparedness. Resilience in rural areas is hinged on productive ecosystems, secure livelihoods, equitable resource access and distribution, and healthy human populations to deal with climatic and socio-economic stressors. These dimensions are closely linked with Biodiversity, which contributes to ecosystem services, agricultural productivity, long-term human well-being, and rural resilience, and thus why ecological conservation and rural resilience are closely linked (Dasgupta, 2021).

2.2 Social-Ecological Systems Perspective

The social-ecological systems approach acknowledges that people's social and ecological lives exist in a complex interconnected system, where changes in the environment have direct implications for livelihoods, food production, and health. Changes in climate due to an increase in temperature, increase in rainfall and increase in extreme weather events change the functioning of the ecosystem and agricultural productivity resulting in changes in food availability and nutrition security. Adaptability of the plants to climate change, such as the loss of crop yields and nutritional quality, highlights the need to incorporate ecological knowledge in planning for resilience and sustainable management of food systems (Janni et al., 2024). This view supports decisions on policies that balance the provision of ecosystem services, improve agricultural sustainability and build resilience of communities to future environmental risks.

2.3 Livelihood and Community Resilience Approaches

Livelihood resilience is about improving the capacity of rural households to maintain their livelihoods, even when climate and economic events have an adverse impact. Agricultural diversification, technological innovations and community collaboration enhance the ability to withstand and bounce back from shocks and decrease reliance on fragile production systems. Precision Livestock Farming technologies are used as examples of how digital monitoring, automation and data-driven management can enhance animal health, reduce resource use and boost farm productivity in the context of changing climate, ensuring more resilient rural livelihoods (Sani et al., 2026). Collective



action, local governance, shared knowledge, and social networks that enable coordinated action during crisis and contribute to long-term sustainability are also important elements of the community scale of resilience. The multi-dimensional framework of rural resilience in Figure 1 includes environmental, agricultural, nutritional, health, social and institutional factors.

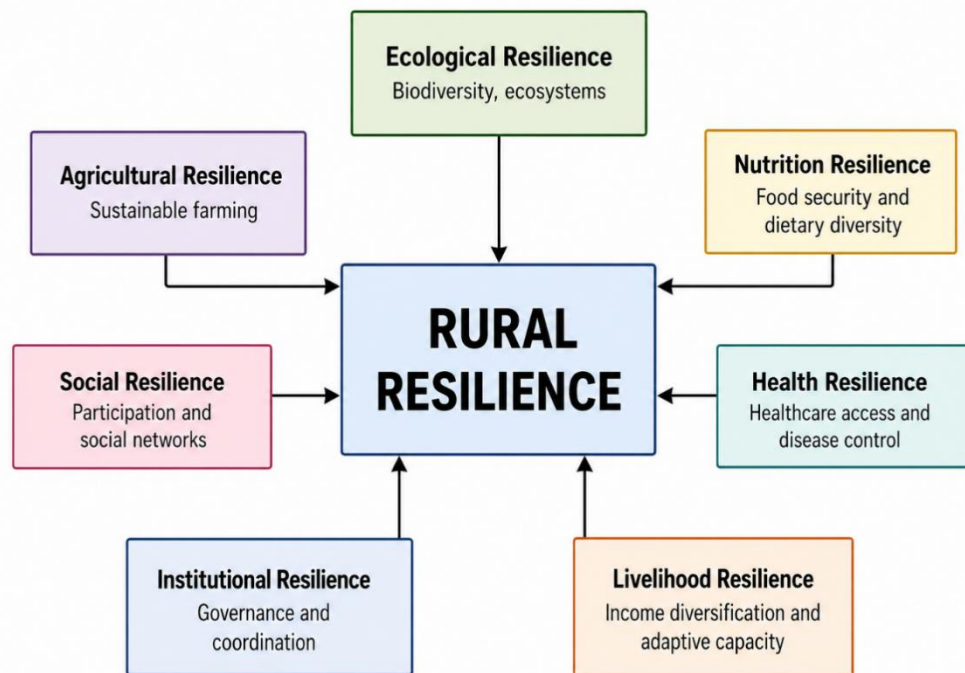


Figure 1. Conceptual Dimensions of Rural Resilience

2.4 Health and Nutrition Resilience

Health and nutrition resilience focuses on communities and health systems capacity to ensure their nutritional status, disease prevention and healthcare services throughout environmental and public health crises. Resilience needs to be built through a combination of surveillance, preventive care, nutrition and flexible provision of services to address several concurrent threats. Recent public health emergencies have shown the critical role of ongoing preventive measures in strengthening resilient health systems, such as vaccination programmes that build immunity in the population and lower its vulnerability in the face of an infectious disease outbreak (Declercq et al., 2024). There is also a greater opportunity to gather timely evidence to track community needs, health outcomes, and food behaviors to plan more responsive resilience, due to the growing use of online surveys to assess nutrition and public health.

2.5 Vulnerability, Adaptive Capacity, and Transformative Capacity

Three key elements are needed to build rural resilience reducing vulnerability, building adaptive capacity, and facilitating long-term transformation. Vulnerability is a measure of exposure to climate and socioeconomic risks, and adaptive capacity is a measure of the ability to adjust practices, technologies and institutions. Transformative capacity helps to create deeper systemic change to enhance sustainability and equity. Healthy lifestyles and policies that support them also enhance the food and nutrition security of vulnerable rural communities, while the use of a One Health approach links human, animal, and environmental health and wellbeing (Bandara et al., 2026; Estrada-Araoz et al., 2025; Organization, 2018). Table 1 provides an overview of key aspects of rural resilience and how they help to adapt to climate change, strengthen nutrition security, and improve community health.



Table 1. Dimensions of Rural Resilience and Their Contributions to Climate–Nutrition–Health Outcomes

Resilience Dimension	Major Components	Contribution to Rural Communities	Reference
Ecological resilience	Biodiversity, ecosystem services	Maintains environmental sustainability	(Dasgupta, 2021)
Agricultural resilience	Climate-smart farming, diversification	Improves food production stability	(Janni et al., 2024)
Health resilience	Primary healthcare, disease prevention	Reduces health risks	(Organization, 2018)
Nutrition resilience	Dietary diversity, food security	Improves nutritional outcomes	(Unicef, 2024)
Social resilience	Community participation, social capital	Enhances adaptive capacity	(Bandara et al., 2026)
Institutional resilience	Governance, coordination	Strengthens disaster preparedness	(Co-operation & Development, 2021)

3. Climate Change and Rural Food Systems

3.1 Climate Variability and Agricultural Productivity

Climate variability is now a key threat to rural food systems, affecting the productivity of crops, soil fertility, water availability, and agricultural stability. Higher temperatures, irregular rainfall, and greater climatic uncertainty are decreasing the efficiency of agriculture and are causing fluctuations in crop production in many areas. Smallholder farmers are particularly impacted as they tend to rely on rain-fed farming and may not have access to climate-adaptive technologies. High rates of agricultural decline lead to increased economic vulnerability in rural households, lower food output and a decrease in resilience and food systems. International assessments have all highlighted the importance of building climate resilience in agriculture to support food production and food security in the long term (FAO & UNICEF, 2019; IFAD, 2019; UNICEF, 2023).

3.2 Droughts, Floods, Heatwaves, and Crop Losses

There are more extreme weather events, such as storms, floods, and droughts, that are negatively impacting agricultural production in significant ways. Droughts lead to less soil moisture and irrigation, floods to loss of standing crops and destruction of agricultural facilities and prolonged heatwaves to diminished plant growth, accelerated evapotranspiration and lower harvest quality. These risks are frequently concurrent with pest infestation and disease pressures and thus add to the risk to rural livelihoods. Climate shocks and stresses affect planting and harvesting seasons, raise production expenses and lower household incomes, especially in more exposed areas where adaptation capabilities are still low. The most recent global food security assessments show that climate disasters have persisted in hindering the progress toward eradicating hunger and malnutrition by affecting the food systems stability and agricultural production (Unicef, 2024).

3.3 Livestock, Fisheries, and Natural Resource Dependence

Rural livelihoods are often reliant on natural resources, such as livestock, fisheries, forests and other natural resources



which are very susceptible to climatic changes. Increased temperatures, shifts in precipitation and the decline of ecosystems impact the health of animals, fish stocks, grazing options and freshwater supplies, which in turn lowers income and diversifies nutrition. As a result of decreasing ecosystem productivity, there is also a reduction in fuelwood, medicinal plants and other resources available to sustain rural livelihoods. The sustainable management of natural resources is thus critical to ensuring resilient food systems and ecosystem services that sustain agricultural production and the well-being of communities. Evidence from around the globe underscores the need for safeguarding natural resource systems as a critical pillar of resilience to future climatic shocks (UNICEF, 2023).

3.4 Food Availability, Accessibility, and Affordability

Climate change affects food security on three levels food availability, physical access and economic access. Farm productivity decreases, and the disruption of transportation and supply chains leads to greater instability of markets and food prices. Because of these changes, low-income rural households have less access to nutritious diets and are at a higher risk of food insecurity. These difficulties are exacerbated by social inequalities, where the poorest and most marginalised populations may have more limited access to healthful foods and have increased nutritional requirements. To tackle inequitable food access, integrated policies that strengthen food distribution systems, local markets, and purchasing power of vulnerable communities are needed (K. R. Schneider et al., 2023). Moreover, the patterns of food supply at the global level aim at nutritional security and environmental sustainability to decrease vulnerabilities to climate change and promote healthier populations (Green et al., 2022). To improve food security, there is also the need for coordinated action and efforts to make food systems more resilient to environmental and economic shocks and stresses (Cardinaals et al., 2025). Table 2 shows the key linkages between climate change and rural food systems and nutrition outcomes.

Table 2. Climate Change Impacts on Rural Food Systems and Nutrition

Climate Driver	Food System Effect	Nutrition Impact	Reference
Rising temperature	Lower crop productivity	Reduced food availability	(Green et al., 2022)
Drought	Water scarcity	Dietary inadequacy	(UNICEF, 2023)
Floods	Supply-chain disruption	Food insecurity	(Unicef, 2024)
Market instability	Higher food prices	Reduced affordability	(J. M. Schneider et al., 2024)
Ecosystem degradation	Declining natural resources	Poor dietary diversity	(Cardinaals et al., 2025)

3.5 Climate-Resilient and Sustainable Agricultural Practices

Resilient rural food systems rely on farming systems that can improve productivity, environmental sustainability, and climate adaptation. Climate-smart farming, efficient water management, crop diversification, conservation agriculture, agroforestry and improved post-harvest management limit vulnerability and contribute to sustainable development. Additionally, food safety is a significant aspect of resilient food systems, and there is an increasing focus on natural compounds derived from plants to manage food-borne pathogens and decrease the use of synthetic preservatives in food value chains (Al Raish, 2026). At the same time, mitigation measures to reduce the emissions of GHGs from agriculture and other agri-related activities are critical to minimize the future climate effects on food production, which must be executed in parallel with adaptation strategies (Haites, 2025). These all combine to enhance the resilience of rural communities in food production, ecosystem health and nutrition under a climate context that is growing ever more unpredictable. The pathways through which climate change impacts agriculture, food systems and nutrition are shown in Figure 2.

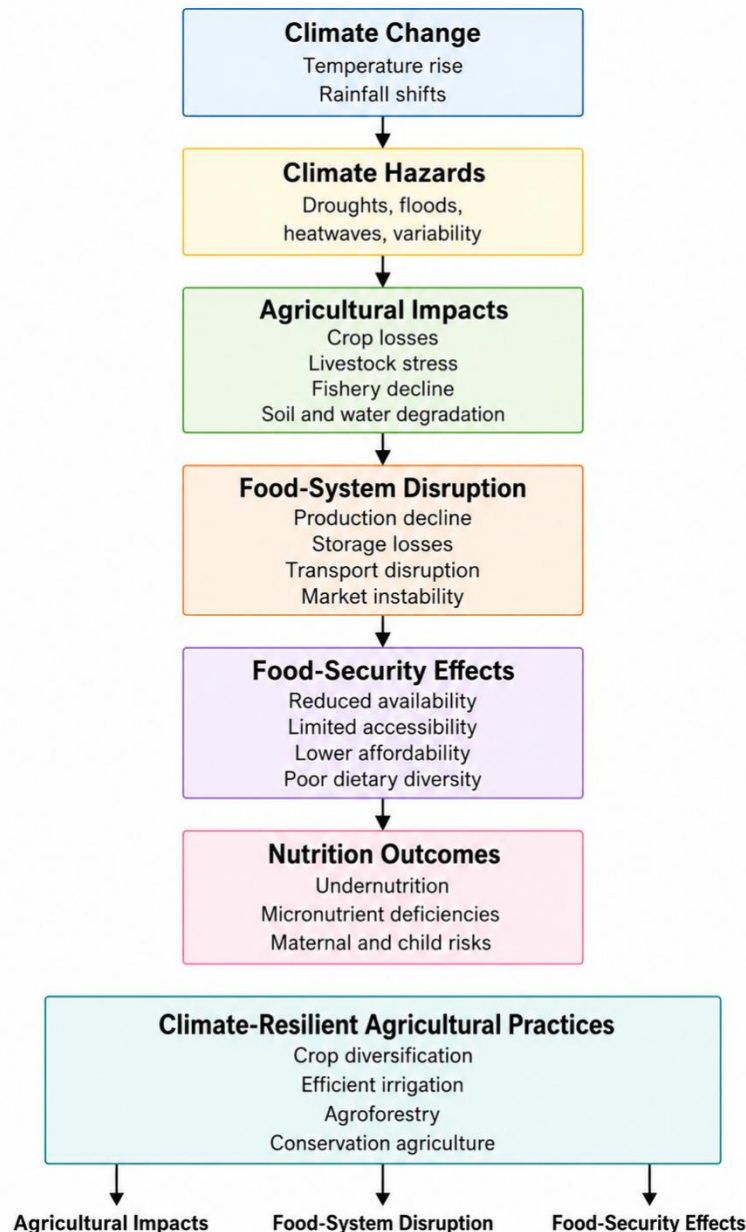


Figure 2. Climate Change Pathways Affecting Rural Food Systems

4. Nutrition Vulnerability and Food Insecurity

4.1 Rural Malnutrition and Micronutrient Deficiencies

Rural communities continue to suffer disproportionately from malnutrition due to shortages of nutritious foods and access to healthcare and clean water, as well as insecurity of livestock and livelihoods. Climate change exacerbates all these challenges, as it lowers agricultural productivity, affects food supply chains and makes poor nutrition more frequent. Rural communities are often confronted with undernutrition, micronutrient deficiencies and overnutrition, a result of the complexity of global nutrition challenges. To tackle these challenges, a holistic approach to public health intervention is needed, encompassing improvements in the food system, nutrition education, dietary changes, and sustainable agriculture for nutrition resilience (Muonde et al., 2024).

4.2 Dietary Diversity and Seasonal Food Shortages

Dietary diversity, which is a key component of nutritional status, is limited in rural areas, especially due to seasonal availability of foods, climatic variability and variability in agricultural production. Limited water supply for producing variety of crops and strong reliance on low-nutrient-value staple crops in droughts, floods and extremes. These seasonal variations are responsible for suboptimal vitamin and mineral intakes, especially for vulnerable households. Climate projections also show that the growing number of extreme weather events further increase the risk of food



insecurity, and that more investment in adaptation measures to stabilize food production and food security year-round, including dietary diversity, is needed (Hasegawa et al., 2021). Additionally, there is growing awareness that improving food environments, by making healthier food options more available and making food healthier, is a critical strategy for improving nutrition and wellbeing (Farrell et al., 2021).

4.3 Maternal and Child Nutrition Risks

Food insecurity and poor nutrition have an impact on those who are most vulnerable, including women, infants, and young children. Undernutrition in women during pregnancy raises the risk of poor birth outcomes and nutrient deficiency in children negatively affects physical development, cognition, and immune system. These risks are exacerbated by food insecurity and disruption of health services due to climate change, which limit access to balanced diets and provision of maternal health services. Therefore, protecting nutrition for women and children demands integrated interventions, encompassing healthcare, nutrition-sensitive agriculture, social protection, and nutrition in communities, to ensure sufficient nutrition during the critical stages of life (Ambikapathi et al., 2022).

4.4 Gender, Poverty, and Unequal Food Distribution

Socioeconomic inequalities, in particular gender and poverty, play an important role in the level of food insecurity. Women are often less likely to have access to productive resources, land ownership, financial services, education and decision-making power, which restricts their capacity to access nutritious food for themselves and their families. High food prices, low and erratic incomes and limited market access are also handicaps for poor households. These inequalities are also shaped by ongoing changes in food systems, which have both positive and negative effects on rural communities in the process of adjusting to urbanisation and market dynamics. Knowing the specifics of these transitions is crucial for creating equitable policies to boost rural livelihoods and enhance food and nutrition security (S. de Bruin et al., 2022; S. P. de Bruin et al., 2021).

4.5 Nutrition-Sensitive Agriculture and Social Protection

Incorporating nutrition goals in agriculture development and social protection policies is essential for increased food system resilience. Nutrition-sensitive agriculture focuses on producing a variety of nutritious food and enhancing household income, environment and nutrition. Climatic and economic shocks can affect vulnerable populations access to sufficient nutrition, which supported by complementary social protection measures such as food assistance, school feeding, cash transfers and livelihood support. Global food security further relies on cooperation in governance systems that integrate agricultural, health and nutrition and environmental policies into a common development agenda (Clapp, 2020). In addition, investing in rural youth education, employment and agricultural innovation will help ensure the long-term sustainability of rural food systems as well as improving the resilience of households to future food security risks (IFAD, 2019).

5. Climate-Related Community Health Risks

5.1 Heat Stress and Occupational Health

Heatwaves are occurring with greater frequency, intensity, and length, and climate change poses a considerable occupational health risk to rural people. The heat stress that agricultural workers, livestock handlers and other outdoor workers encounter causes them to become exhausted, dehydrated, less productive and more vulnerable to chronic diseases and illnesses. Also as temperatures increase the safe working hours decrease and production in agriculture decreases, impacting health and livelihoods. Global warming continue to increase health risks due to heat exposure, particularly if adaptation and mitigation strategies are not put in place at the local, national and international level (Allan et al., 2023). The results support the need to consider the inclusion of occupational health protection in the climate resilience planning of rural communities.

5.2 Waterborne, Vector-Borne, and Infectious Diseases

The distribution and transmission of infectious diseases can change due to changes in climatic conditions which affect temperature, rainfall, humidity, and ecosystem characteristics. Warm weather extends disease vectors range, such as mosquitoes and ticks, leading to the spread of malaria, dengue, and other vector-borne diseases, and flooding affects drinking water sources. Rural people are likely to be more vulnerable because of poor environmental sanitation, limited health care facilities and inadequate surveillance. Health effects from climate change are not just from direct exposure to climate change but also include the risk of outbreaks of infectious diseases, which underscores the need for integrated adaptation strategies in health, agriculture and environment sectors (Bongaarts, 2024).

5.3 Water, Sanitation, and Hygiene Challenges

Water safety, sanitation and hygiene are key drivers of community health, which are increasingly under threat from



climate change. Droughts decrease the amount of freshwater available and floods destroy sanitation facilities and pollute water supplies, thus escalating the incidence of diarrheal diseases and other water-related diseases. Preserving soil quality through sustainable land management also helps to improve water retention, soil erosion control, and resilience of ecosystems, which in turn helps to create a healthier environment for rural populations. Conservation agriculture has proven to be very promising to enhance soil security and ensure the sustainability of agriculture in the face of changing climatic conditions (Mugandani et al., 2021). In the same way, sustainable farming practices for vegetable oilseed, as climate-resilient innovations, play a crucial role in ensuring food system stability, protecting the environment, and enhancing long-term community health (Bihani et al., 2026). The relationships between climate stressors, nutrition, environmental health and community well-being are illustrated in Figure 3.

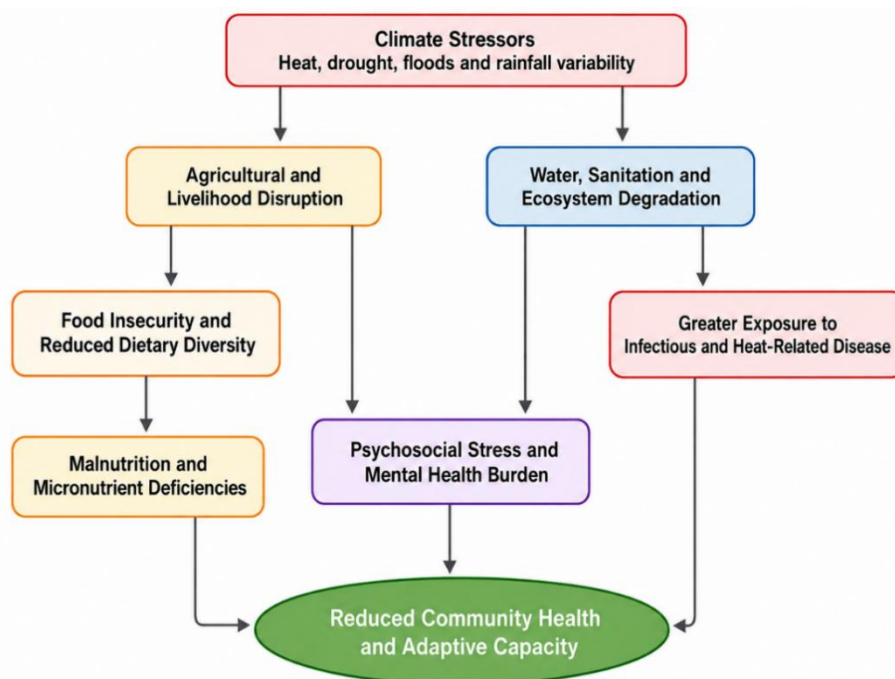


Figure 3. Interactions Between Climate, Nutrition, and Community Health

5.4 Mental Health and Psychosocial Stress

Climate-related disasters have a significant psychological impact on rural populations due to displacement, loss of livelihoods, food insecurity, and an uncertain future environmental situation. Climate stressors can lead to anxiety and depression, emotional distress and lower quality of life, especially in the vulnerable population of older adults. Cognitive health also emerge as a growing public health issue, as aging populations are likely to be exposed to more than one environmental or socioeconomic factor. Global burden estimates reveal the increasing burden of dementia globally, highlighting the need for resilient health systems to be able to tackle both mental and neurological health problems and the risks of climate change (Nichols et al., 2022). It is therefore important that community-based psychosocial support and mental health services be an integral part of climate resilience planning.

5.5 Access to Rural Healthcare and Essential Services

In many rural areas, access to healthcare is still not extensive because of the shortage of healthcare professionals, lack of transportation facilities, poor infrastructure and limited financial resources. Climate-related disasters often cause delays in health care provision, with damage to health care facilities, disruptions to supply chain, and limited access to medicines and nutrition support. Improving access to health care need an integrated rural development policy, which involve upgrading infrastructure, building up healthcare workers capacities, and enhancing service delivery and encouraging knowledge sharing and innovation. Smallholder agriculture and rural development studies also highlight how investing in rural populations and institutions crucial to enhancing health outcomes and resilience to future environmental shocks (McCarthy et al., 2023). Additionally, food security is an important health care objective to address the long-term health inequalities during preconception, pregnancy, and early childhood (Hurley et al., 2026).

5.6 Health-System Preparedness for Climate Emergencies

Health systems need to be able to adapt, plan for, respond to, and recover from a growing number of environmental crises to become climate resilient. This involves early warning systems, emergency response planning, resilient health



care infrastructure, good disease surveillance and multi-sector coordinated governance. Incorporating climate adaptation into health policy also entails bolstering nutrition programs, encouraging sustainable agricultural systems, and enhancing food systems resilience to minimize the climate-sensitive risks to health. However, climate change has a direct impact on agricultural productivity and the income of households, and for long-term nutrition security, coordinated interventions are needed that take into account environmental and socioeconomic vulnerability. There is evidence that income growth cannot counter the nutritional impacts of climate change without additional investments in resilient food systems and adaptive public health efforts (Nelson et al., 2018). This means that robust preparedness approaches and strategies which include health, nutrition, agriculture and environmental management are needed to safeguard vulnerable rural populations in future climate scenarios. Table 3 provides an overview of the most significant climate change-related health risks and some recommended adaptation measures.

Table 3. Climate-Related Community Health Risks and Adaptation Measures

Health Risk	Climate Driver	Adaptation Strategy	Reference
Heat stress	Heatwaves	Occupational safety measures	(Allan et al., 2023)
Waterborne diseases	Flooding	Safe water and sanitation	(Mugandani et al., 2021)
Vector-borne diseases	Rising temperature	Disease surveillance	(Bongaarts, 2024)
Mental health problems	Climate disasters	Community psychosocial support	(Nichols et al., 2022)
Food insecurity	Crop failure	Nutrition-sensitive interventions	(Nelson et al., 2018)

6. Developing a Holistic Climate-Nutrition-Health Resilience Framework

6.1 Core Components of the Proposed Framework

A comprehensive climate-nutrition-health resilience framework brings together environmental sustainability, food system, nutrition, health, governance, and community involvement for a more integrated approach to enhance rural resilience. The framework does not stand alone but acknowledges that food security and health risks are intricately linked with climate change and need to be addressed through multisectoral action. The ability to anticipate, adapt and recover from climatic shocks, combined with a balance of ecological conservation, economic development, public health and social equity, is essential to effective resilience. There is thus a need for policy coherence across agriculture, nutrition, environment and health sectors, for achieving sustainable and resilient food systems (Co-operation & Development, 2021). Table 4 provides a summary of the important components and indicators to be incorporated in the proposed resilience framework.

Table 4. Components of the Proposed Climate–Nutrition–Health Resilience Framework

Framework Component	Key Indicator	Expected Outcome	Reference
Sustainable agriculture	Crop productivity	Food security	(Springmann et al., 2018)
Nutrition security	Dietary diversity	Better nutritional status	(Pérez-Escamilla & Moran, 2022)
Water security	Safe water access	Reduced disease burden	(Choudhary et al., 2025)



Community participation	Social engagement	Stronger resilience	(Unicef, 2024)
Governance	Institutional coordination	Improved emergency response	(Co-operation & Development, 2021)
Ecosystem protection	Biodiversity conservation	Sustainable livelihoods	(J. M. Schneider et al., 2024)

6.2 Climate-Resilient Livelihoods and Food Systems

Resilient livelihoods are the backbone of sustainable rural development in the context of environmental uncertainty as they enable households to continue producing food and income. Climate-resilient food systems lead to diversified agriculture, sustainable land management, efficient use of resources, and environmentally friendly food production, while minimizing climate risks. However, long-term sustainability attained only through balancing the growing demand of the population with limited natural resources, which highlights the need to consider environmental conservation in rural development plans (Pradhan, 2026). In addition, within-ecological limit food systems are important to ensure future food security and environmental protection through sustainable production and consumption (Springmann et al., 2018).

6.3 Nutrition Security and Community-Based Health Services

Adequate nutrition plays a direct role in immunity, physical development, disease resistance, and community well-being, and should be central in resilience planning. The provision of community-based health services can contribute to resilience through the provision of nutrition education, maternal and child health services, nutrition preventive interventions and routine nutrition surveillance at the community level. Special focus should be paid to target groups that are especially vulnerable to the nutrition impact of food insecurity and climate change. Incorporating maternal and child nutrition plans into the adaptation plans improve immediate and long-term health outcomes and intergenerational vulnerability (Pérez-Escamilla & Moran, 2022). Furthermore, examining nutrition transitions can offer insights into designing culturally relevant interventions that take into account traditional nutrition systems and respond to new nutrition challenges (Marinho et al., 2026).

6.4 Water, Sanitation, Infrastructure, and Ecosystem Protection

The availability of safe water, proper sanitation, robust infrastructure, and a healthy environment are essential to safeguarding public health and ensuring sustainable food production. These systems are vulnerable to climate change, which lead to water shortages, ecosystem loss, and rural infrastructure damage, and therefore to disease and food insecurity. While ensuring long-term agricultural productivity, sustainable land-use planning and conservation policies can help safeguard biodiversity and ecosystem services and avoid environmentally harmful agricultural expansion (Choudhary et al., 2025; J. M. Schneider et al., 2024). Water security is also a crucial pathway between climate change and nutrition outcomes, where increases in water availability and management can lead to greater climate–nutrition resilience.

6.5 Local Knowledge, Community Participation, and Social Networks

The role of local people in planning, implementing and evaluating adaptation strategies increases the resilience of the community. Indigenous knowledge, traditional farming techniques and locally developed coping strategies are important sources of information and culturally appropriate and context-specific solutions in dealing with climatic variability. Well-developed social networks promote cooperation, sharing of information, mutual support and community action in the event of an environmental crisis, enhancing adaptive capacity and long-term community resilience.

6.6 Governance, Institutional Coordination, and Early-Warning Systems

Good governance includes coordinated institutional arrangements, including between agriculture, environment, nutrition, health and disaster management institutions, to enable integrated responses to climate challenges. Early-warning systems, climate information services, preparedness for emergencies and evidence-based policy making are all essential for timely interventions that minimise human and economic losses. Interinstitutional cooperation also helps in the effective use of resources, coordinated disaster response, and long-term disaster resilience planning (Allan et al., 2023; Valavanidis, 2023). Food systems are constantly changing as part of the climate change process, and governance structures need to be flexible enough to accommodate technological advances, especially with the emergence of sustainable food preparation processes and energy-efficient community services (Khalifa et al., 2026).



6.7 Indicators for Measuring Resilience Outcomes

Resilience assessment must be done in several dimensions and encompass environmental, nutritional, health, economic and social outcomes. The food security status, dietary diversity, nutritional health, agricultural productivity, water accessibility, ecosystem condition, healthcare availability, household adaptive capacity and institutional preparedness may be appropriate indicators. By tracking these indicators, policymakers assess the effectiveness of interventions, identify potential vulnerabilities, and continuously enhance resilience strategies. A robust indicator system enables decisions to be made based on evidence and helps ensure that the implementation of climate adaptation actions also supports sustainable development, nutrition security, environmental protection and community health (Hayes & Poland, 2018). The proposed holistic resilience framework is shown in Figure 4, which incorporates climate adaptation, nutrition security, community health, ecosystem protection, governance and sustainable rural development.

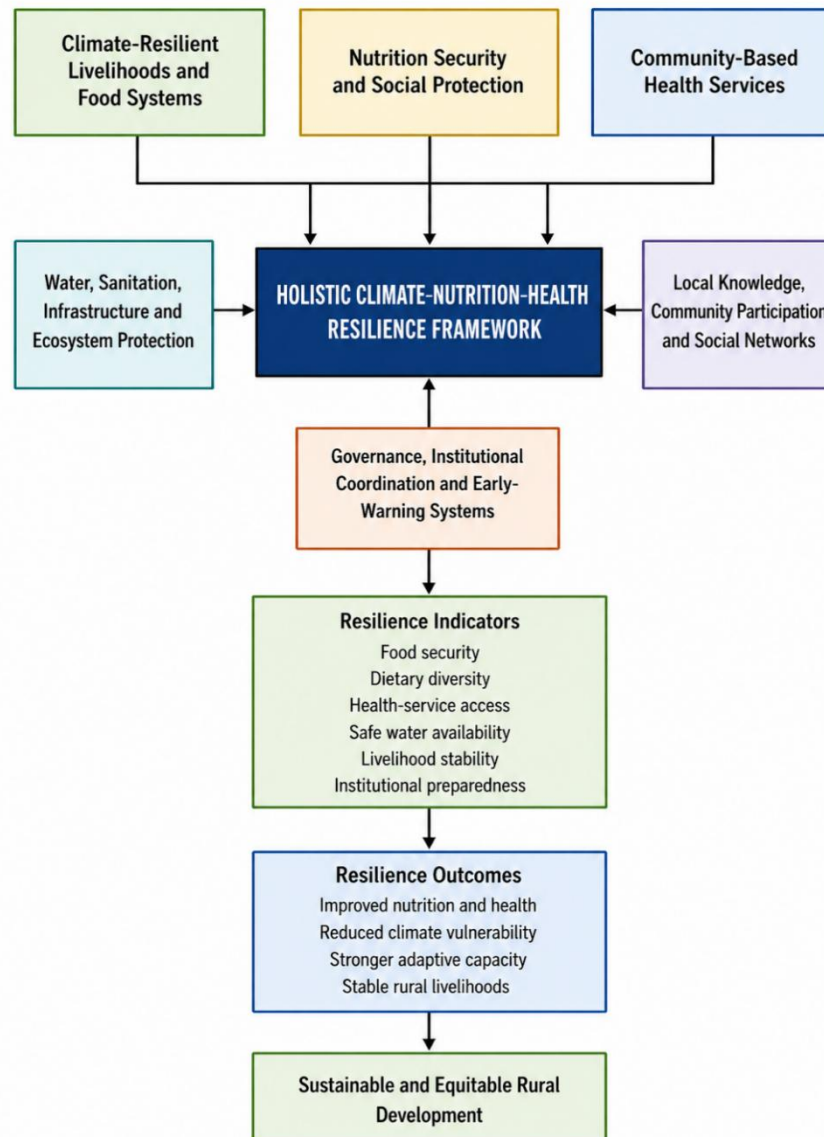


Figure 4. Holistic Climate–Nutrition–Health Resilience Framework for Vulnerable Rural

7. Implementation Challenges, Policy Implications, and Future Research

7.1 Financial, Institutional, and Technological Barriers

The adoption of a comprehensive climate-nutrition-health resilience model is still a challenge as most of the rural areas have experienced long-term financial limitations, low institutional capacities and unequal access to modern technologies. Inequitable investment in climate adaptation, health facilities, sustainable farming, and digitalization limits how vulnerable populations can react to climate-based disasters. Increasing poverty also exacerbates these



issues through limiting the ability of households to engage in resilient agriculture and to access basic health and nutrition services. International data show that rising rates of severe poverty are still eroding the sustainable development agenda and negating resiliency in vulnerable communities (Valavanidis, 2023). These barriers need long-term investment, strengthening of institutions, and fair access to innovative technologies to overcome them.

7.2 Inclusion of Women, Children, Indigenous Groups, and Marginalized Households

Inclusive resilience policies need to focus on those populations that are disproportionately exposed to climate and food security risks. Women, children, Indigenous communities, and older adults as well as economically disadvantaged households tend to have fewer resources to adapt to and have higher nutritional and health vulnerability. The policies must consequently reinforce social protection, enhance access to education and health, as well as encourage equal involvement in the decision-making process. Child protection, nutrition, and equitable development remain fundamental elements of sustainable resilience promoted by international organizations, and the need to focus on specific interventions that do not leave any vulnerable group behind (Canton, 2021b).

7.3 Policy Integration across Agriculture, Nutrition, Health, and Climate Sectors

The interrelated climate, nutrition, and health issues cannot be resolved without cohesive policies, which can no longer be limited to the conventional sectoral lines. Integrated governance facilitates better resource allocation, reduces policy fragmentation and enhances cooperation between agricultural, environmental, nutrition and healthcare institutions. International environmental efforts are gradually advancing ecosystem preservation, effective utilization of resources and adaptation to climate by using integrated policy measures that enable resilience and sustainable development over the long-term (Citaristi, 2022). In the same vein, human development strategies focus on the need to balance environmental sustainability with health, equity, and socioeconomic development to enhance resilience in the Anthropocene (Conceição, 2020).

7.4 Role of Digital Technologies and Climate Information Services

Digital technologies have also become useful in enhancing resilience in rural areas through climate prediction, agricultural decision-making, disease surveillance, and nutrition surveillance. Climate information services, mobile advisory systems, remote sensing, and early-warning systems provide farmers and local authorities with the ability to predict climatic risks and take early adaptation action. The increase in digital infrastructure and the rise in technological literacy will not only promote evidence-based decision-making but also contribute to the effectiveness of resilience interventions among vulnerable rural communities (Crises, 2024).

7.5 Monitoring, Evaluation, and Scaling of Resilience Interventions

Successful resilience initiatives must be constantly monitored and assessed with multidimensional indicators that reflect the environmental, nutritional, health, and socioeconomic outcomes. Systematic evaluation helps policymakers to determine effective interventions, to enhance implementation plans, and to manage resources effectively. Simultaneously, enhancing the quality of healthcare and patient safety must also be part and parcel of resilience planning so that health systems could remain operational in the face of climate-related disasters and humanitarian disasters (Canton, 2021a; Organization, 2021). The political commitment, institutional cooperation, and involvement of the community are also necessary to scale up successful interventions.

7.6 Research Gaps and Future Directions

Although there is an increasing body of research on climate resilience, there are significant knowledge gaps concerning the interactions between climate change and nutrition, as well as community health and rural livelihoods in the long term. Future studies must create combined assessment models, test community-based adaptation models, and explore how multisectoral resilience interventions work in different geographical and socioeconomic contexts. Food crises, migration, and inequality caused by climate should be given more attention as well to comprehend more about the emerging vulnerabilities. Recent international evaluations indicate that climate change is further deepening food insecurity and humanitarian crises and point to the importance of interdisciplinary research that can inform policy and sustainable resilience options.

8. Conclusion

Climate change has persistently transformed rural livelihoods by both positively affecting food systems, nutritional status, environmental sustainability, and community health. This study has proved that these challenges are highly interrelated and, as a result, they need concerted but not isolated answers. An inter-disciplinary climate-nutrition-health resilience paradigm provides a viable way of enhancing adaptive capacity by means of sustainable agriculture, nutrition-sensitive interventions, resilient health care systems, ecosystem conservation, good water management, and inclusive community engagement. The focus on local knowledge, fair governance, and cross-sectoral partnership can



significantly enhance the resilience of the at-risk rural people and minimize their vulnerability to climate-related risks. Another point that is raised in the study is that resilience is not a fixed state of affairs but a dynamic process, which requires continuous adaptation, innovation, and institutional learning. Enhancing early-warning, digital climate services, social protection mechanisms, and evidence-based policymaking will increase future environmental and social health emergencies preparedness further. Financial, technological and institutional obstacles continue to be substantial, but the integration of policies and investments in the areas of agriculture, nutrition, health, and the environment can produce sustainable changes in well-being in rural areas. Finally, to build resilient rural populations, there must be a balance between ecological and human development and food security, nutritional health and environmental management must support each other. This kind of all-inclusive and multi-disciplinary approach will be critical towards long-term resilience, limiting inequalities, and supporting sustainable development in a more uncertain climate.

References

1. Al Raish, S. M. (2026). The efficacy of plant extracts against key food-borne pathogens: A mechanistic, applications, and advances. *Microorganisms*, 14(3), 621.
2. Allan, R. P., Arias, P. A., Berger, S., Canadell, J. G., Cassou, C., Chen, D., Cherchi, A., Connors, S. L., Coppola, E., & Cruz, F. A. (2023). Intergovernmental panel on climate change (IPCC). Summary for policymakers. In *Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change* (pp. 3–32). Cambridge University Press. https://pure.mpg.de/rest/items/item_3565224/component/file_3565229/content
3. Ambikapathi, R., Schneider, K. R., Davis, B., Herrero, M., Winters, P., & Fanzo, J. C. (2022). Global food systems transitions have enabled affordable diets but had less favourable outcomes for nutrition, environmental health, inclusion and equity. *Nature Food*, 3(9), 764–779.
4. Arora, P. K., Tripathi, S., Omar, R. A., Chauhan, P., Sinhal, V. K., Singh, A., Srivastava, A., Garg, S. K., & Singh, V. P. (2024). Next-generation fertilizers: The impact of bionanofertilizers on sustainable agriculture. *Microbial Cell Factories*, 23(1), 254. <https://doi.org/10.1186/s12934-024-02528-5>
5. Bandara, S., Oishi, W., Amarasiri, M., Nochi, T., Saito, M., Mitani, A. A., Nguyen, T. H., & Sano, D. (2026). Causal inference for targeted public health interventions: Interactions among environmental, social, and economic determinants within the one health framework. *Journal of Water and Health*, 24(6), 759–772.
6. Béné, C., Bakker, D., Chavarro, M. J., Even, B., Melo, J., & Sonneveld, A. (2021). Global assessment of the impacts of COVID-19 on food security. *Global Food Security*, 31, 100575.
7. Bihani, M., Bhutada, P. G., Rajendran, R., Almoselhy, R. I., Channakeshava, M., Manjunath, K. B., Babu, N. R., & Thomas, S. (2026). Innovative approaches for climate-resilient vegetable oilseed farming towards sustainable edible oil production: A systematic review. https://www.researchgate.net/profile/Rania-Almoselhy/publication/406490293_Innovative_approaches_for_climate-resilient_vegetable_oilseed_farming_towards_sustainable_edible_oil_production_A_systematic_review/links/6a27f110d551e312d71f8bb5/Innovative-approaches-for-climate-resilient-vegetable-oilseed-farming-towards-sustainable-edible-oil-production-A-systematic-review.pdf
8. Bongaarts, J. (2024). IPCC, 2023: Climate Change 2023: Synthesis Report. IPCC, 184 p., doi: <https://doi.org/10.59327/IPCC/AR6-9789291691647>. *Population and Development Review*, 50(2), 577–580. <https://doi.org/10.1111/padr.12632>
9. Canton, H. (2021a). International fund for agricultural development—IFAD. In *The Europa directory of international organizations 2021* (pp. 330–332). Routledge. <https://api.taylorfrancis.com/content/chapters/edit/download?identifierName=doi&identifierValue=10.4324/9781003179900-48&type=chapterpdf>
10. Canton, H. (2021b). United Nations Children’s Fund—UNICEF. In *The Europa directory of international organizations 2021* (pp. 160–172). Routledge. <https://www.taylorfrancis.com/chapters/edit/10.4324/9781003179900-25/united-nations-children-fund%E2%80%94unicef-helen-canton>
11. Cardinaals, R. P. M., Bubnyte, G., & Huppertz, T. (2025). Global Food Security. https://www.researchgate.net/profile/Renee_Cardinaals/publication/397917589_The_protein_transition_into_context_-_the_impact_of_dietary_shifts_in_different_countries_on_nutritional_adequacy_of_diets/links/693440f627359023a009b049/The-protein-transition-into-context-the-impact-of-dietary-shifts-in-different-countries-on-nutritional-adequacy-of-diets.pdf
12. Choudhary, N., Brewis, A., & Wutich, A. (2025). Climate-Nutrition Interaction: Identifying the Mediating Roles of Water Security Using Nationally-Representative Indian Data. *Water Scarcity and Drought*, 1(1), 3.
13. Citaristi, I. (2022). United nations environment programme—UNEP. In *The Europa directory of international organizations 2022* (pp. 193–199). Routledge.



- <https://www.taylorfrancis.com/chapters/edit/10.4324/9781003292548-46/united-nations-environment-programme%E2%80%9494unep-ileana-citaristi>
14. Clapp, J. (2020). Food security and nutrition: Building a global narrative towards 2030. <https://openknowledge.fao.org/items/2d9c0374-650b-4880-a7f4-5a8cc140a2ba>
 15. Conceição, P. (2020). Human development report 2020-the next frontier: Human development and the anthropocene. United Nations Development Programme: Human Development Report. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4418010
 16. Co-operation, O. for E. & Development. (2021). Making better policies for food systems. OECD Publishing.
 17. Crises, G. N. A. F. (2024). Food security & climate: High level messaging on the global report on food crises 2024. <https://cgspace.cgiar.org/bitstreams/f34bc758-a4d1-4a0e-a702-8eb6a43a4fc0/download>
 18. Dasgupta, P. (2021). The Economics of Biodiversity: The Dasgupta. London: HM Treasury. <https://www.vliz.be/imisdocs/publications/377863.pdf>
 19. de Bruin, S., Dengerink, J., Randhawa, P., Wade, I., Biemans, H., & Siderius, C. (2022). IFAD Research Series 71: Urbanizing food systems: exploring opportunities for rural transformation. <https://ageconsearch.umn.edu/record/320721/>
 20. de Bruin, S. P., Dengerink, J., Randhawa, P., Wade, I., Biemans, H., & Siderius, C. (2021). Urbanising food systems: Exploring opportunities for rural transformation. Background Papers for the Rural Development Report 2021. <https://www.academia.edu/download/85845157/RS71.pdf>
 21. Declercq, J., Gerlo, S., Van Nevel, S., De Ruyck, N., Holtappels, G., Delesie, L., Tobback, E., Lammens, I., Gerebtsov, N., Sedeyn, K., Saelens, X., Lambrecht, B. N., Gevaert, P., Vandekerckhove, L., & Vanhee, S. (2024). Repeated COVID-19 mRNA-based vaccination contributes to SARS-CoV-2 neutralizing antibody responses in the mucosa. *Science Translational Medicine*, 16(770), eadn2364. <https://doi.org/10.1126/scitranslmed.adn2364>
 22. Estrada-Araoz, E. G., Quispe-Aquise, J., Ayay-Arista, G., Chura-Quispe, G., Quipo-Conde, N. A., Rivera-Mamani, F. A., & Mamani-Roque, M. (2025). Perceived Barriers to Physical Activity in a Sample of University Students: A Descriptive Study. *Educational Process: International Journal*, 15, e2025130.
 23. FAO, I. & UNICEF. (2019). WFP and WHO, 2017. The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security. Rome, FAO. Retrived 12/06/2018, from <http://www.fao.org/3/a-17695e.pdf>.
 24. Farrell, P., Rachmi, C. N., Mulcahy, G., Helble, M., & Thow, A. M. (2021). Food environment research is needed to improve nutrition and well-being in Asia and the Pacific. *Public Health Nutrition*, 24(14), 4706–4710.
 25. Green, R., Scheelbeek, P., Bentham, J., Cuevas, S., Smith, P., & Dangour, A. D. (2022). Growing health: Global linkages between patterns of food supply, sustainability, and vulnerability to climate change. *The Lancet Planetary Health*, 6(11), e901–e908.
 26. Haites, E. (2025). Mitigating Greenhouse Gas Emissions-the Big Picture. Submitted for Peer Review. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5245230
 27. Hasegawa, T., Sakurai, G., Fujimori, S., Takahashi, K., Hijioka, Y., & Masui, T. (2021). Extreme climate events increase risk of global food insecurity and adaptation needs. *Nature Food*, 2(8), 587–595.
 28. Hayes, K., & Poland, B. (2018). Addressing mental health in a changing climate: Incorporating mental health indicators into climate change and health vulnerability and adaptation assessments. *International Journal of Environmental Research and Public Health*, 15(9), 1806.
 29. Hurley, K., McNee, R., Bryant, M., Akhter, Z., Bell, Z., Farrand, C., Frank, L., Grainge, S., Heslehurst, N., & McKerracher, L. J. (2026). Recommendations for Action on Food Insecurity in High-Income Countries for Preconception, Pregnancy and Early Childhood: A Modified Delphi Study. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6478361
 30. IFAD, B. W. (2019). Papers of the 2019 Rural Development Report-Rural youth, today.
 31. Jackson, J. S., Kantamaneni, K., Ganeshu, P., Sunkur, R., & Rathnayake, U. (2025). Assessment of the role of nanotechnology in water sector: An expert opinion. *International Journal of Energy and Water Resources*, 9(4), 1645–1667. <https://doi.org/10.1007/s42108-025-00389-1>
 32. Janni, M., Maestri, E., Gulli, M., Marmiroli, M., & Marmiroli, N. (2024). Plant responses to climate change, how global warming may impact on food security: A critical review. *Frontiers in Plant Science*, 14, 1297569.
 33. Khalifa, Y., Todd, J. F., & Leach, M. (2026). Can eCooking Cope with Changes in School Meals Driven by the Global Food Systems Transformation and Climate Change? <https://mecs.org.uk/blog/can-ecooking-cope-with-changes-in-school-meals-driven-by-the-global-food-systems-transformation-and-climate-change/>
 34. Marinho, T., Gall, A., Armour, D., & Williams, L. (2026). Following the Tracks-Nutrition Transition for Indigenous People in Australia. Available at SSRN 7045679. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=7045679
 35. McCarthy, N., Cavatassi, R., & Mabiso, A. (2023). The IFAD Research Series has been initiated by the Strategy and Knowledge Department in order to bring together cutting-edge thinking and research on smallholder agriculture, rural development and related themes. As a global organization with an exclusive mandate to promote rural



- smallholder development, IFAD seeks to present diverse viewpoints from across the development arena in order to stimulate knowledge exchange, innovation, and commitment to investing in rural people. <https://www.academia.edu/download/99369863/RS89.pdf>
36. Mugandani, R., Mwadzingeni, L., & Mafongoya, P. (2021). Contribution of conservation agriculture to soil security. *Sustainability*, 13(17), 9857.
 37. Muonde, M., Olorunsogo, T. O., Ogugua, J. O., Maduka, C. P., Omotayo, O., Muonde, M., Olorunsogo, T. O., Ogugua, J. O., Maduka, C. P., & Omotayo, O. (2024). Global nutrition challenges: A public health review of dietary risks and interventions. *World Journal of Advanced Research and Reviews*, 21(1), 1467–1478.
 38. Nelson, G., Bogard, J., Lividini, K., Arsenault, J., Riley, M., Sulser, T. B., Mason-D'Croz, D., Power, B., Gustafson, D., & Herrero, M. (2018). Income growth and climate change effects on global nutrition security to mid-century. *Nature Sustainability*, 1(12), 773–781.
 39. Nichols, E., Steinmetz, J. D., Vollset, S. E., Fukutaki, K., Chalek, J., Abd-Allah, F., Abdoli, A., Abualhasan, A., Abu-Gharbieh, E., & Akram, T. T. (2022). Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: An analysis for the Global Burden of Disease Study 2019. *The Lancet Public Health*, 7(2), e105–e125.
 40. Organization, W. H. (2018). The state of food security and nutrition in the world 2018: Building climate resilience for food security and nutrition. Food & Agriculture Org. [https://books.google.com/books?hl=en&lr=&id=LC9uDwAAQBAJ&oi=fnd&pg=PA3&dq=FAO.+\(2018\).+The+State+of+Food+Security+and+Nutrition+in+the+World+2018.+FAO.&ots=0OfwrCgYLp&sig=Gc-PkytYMu6D8He6B6JeYYDdKag](https://books.google.com/books?hl=en&lr=&id=LC9uDwAAQBAJ&oi=fnd&pg=PA3&dq=FAO.+(2018).+The+State+of+Food+Security+and+Nutrition+in+the+World+2018.+FAO.&ots=0OfwrCgYLp&sig=Gc-PkytYMu6D8He6B6JeYYDdKag)
 41. Organization, W. H. (2021). Global patient safety action plan 2021-2030: Towards eliminating avoidable harm in health care. World Health Organization. [https://books.google.com/books?hl=en&lr=&id=csZqEAAAQBAJ&oi=fnd&pg=PR7&dq=World+Bank.+\(2021\).+Climate+Change+Action+Plan+2021%E2%80%932025.+World+Bank.&ots=xKY_aZgqyr&sig=hF2qdWlovEP1eLF82INVABHb41c](https://books.google.com/books?hl=en&lr=&id=csZqEAAAQBAJ&oi=fnd&pg=PR7&dq=World+Bank.+(2021).+Climate+Change+Action+Plan+2021%E2%80%932025.+World+Bank.&ots=xKY_aZgqyr&sig=hF2qdWlovEP1eLF82INVABHb41c)
 42. Pérez-Escamilla, R., & Moran, V. H. (2022). Maternal and child nutrition must be at the heart of the climate change agendas. *Maternal & Child Nutrition*, 19(1), e13444.
 43. Popkin, B. M., Corvalan, C., & Grummer-Strawn, L. M. (2020). Dynamics of the double burden of malnutrition and the changing nutrition reality. *The Lancet*, 395(10217), 65–74.
 44. Pradhan, B. (2026). A Survey of Population Growth Versus Resources and Sustainability Debate. *Nepal Population Journal*, 19(1), 76–87.
 45. Sani, M. I., van der Voort, M., Tekinerdogan, B., & Hogeveen, H. (2026). Application of precision livestock farming: Challenges and opportunities. *Animal Bioscience*, 39(4), 250895.
 46. Schneider, J. M., Delzeit, R., Neumann, C., Heimann, T., Seppelt, R., Schuenemann, F., Söder, M., Mauser, W., & Zabel, F. (2024). Effects of profit-driven cropland expansion and conservation policies. *Nature Sustainability*, 7(10), 1335–1347.
 47. Schneider, K. R., Bellows, A., Downs, S., Bell, W., Ambikapathi, R., Nordhagen, S., Branca, F., Masters, W. A., & Fanzo, J. C. (2023). Inequity in access to healthy foods. <https://www.research.ed.ac.uk/en/publications/inequity-in-access-to-healthy-foods/>
 48. Segnon, A. C., Totin, E., Zougmore, R. B., Lokossou, J. C., Thompson-Hall, M., Ofori, B. O., Achigan-Dako, E. G., & Gordon, C. (2021). Differential household vulnerability to climatic and non-climatic stressors in semi-arid areas of Mali, West Africa. *Climate and Development*, 13(8), 697–712. <https://doi.org/10.1080/17565529.2020.1855097>
 49. Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., De Vries, W., Vermeulen, S. J., Herrero, M., & Carlson, K. M. (2018). Options for keeping the food system within environmental limits. *Nature*, 562(7728), 519–525.
 50. UNICEF. (2023). The state of food security and nutrition in the world 2023. <https://openknowledge.fao.org/items/445c9d27-b396-4126-96c9-50b335364d01>
 51. Unicef. (2024). The state of food security and nutrition in the world 2024. <https://openknowledge.fao.org/items/ebe19244-9611-443c-a2a6-25cec697b361>
 52. Valavanidis, A. (2023). World Bank Report: Extreme Poverty is Rising Again. From 660 Million People (8.5% World Population) in 2019 to 733 Million In, 2022(1), 1.
 53. Wahab, S., Muzammil, K., Nasir, N., Khan, M. S., Ahmad, M. F., Khalid, M., Ahmad, W., Dawria, A., Reddy, L. K. V., & Busayli, A. M. (2022). Advancement and new trends in analysis of pesticide residues in food: A comprehensive review. *Plants*, 11(9), 1106.
 54. Wood, A., Queiroz, C., Deutsch, L., González-Mon, B., Jonell, M., Pereira, L., Sinare, H., Svedin, U., & Wassénus, E. (2023). Reframing the local–global food systems debate through a resilience lens. *Nature Food*, 4(1), 22–29.