

## Original Research Article

# Climate-Smart Agriculture and Public Health Resilience: A Critical Review

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### Article Information:

Received: 09 December 2025 | Revised: 14 January 2026 | Accepted: 10 February 2026 | Published: March 17, 2026

### Cite this article:

Moinuddin, Ateeq Khan, Sarthak Verma, Prerna Negi, Meghna Samanta, Siddhartha Acharya (2026) Climate-Smart Agriculture and Public Health Resilience: A Critical Review *Public Health Open Journal*. 11(1):177–183.

<https://doi.org/10.17140/PHOJ.11.01.177>

### Abstract

Climate change poses significant challenges to global food systems and public health, necessitating innovative and sustainable approaches to agriculture. Climate-Smart Agriculture (CSA) has emerged as a holistic framework that integrates agricultural productivity, climate adaptation, and mitigation strategies while enhancing resilience. This review critically examines the role of CSA in strengthening public health resilience, particularly in vulnerable and resource-limited communities. The study highlights how CSA practices, such as conservation agriculture, agroforestry, water-efficient irrigation, and climate-resilient crop varieties, contribute to improved food security, nutritional outcomes, and environmental sustainability. Additionally, the review explores the interconnections between climate change, agricultural practices, and health risks, including malnutrition, heat stress, vector-borne diseases, and water-related illnesses. CSA approaches can mitigate these risks by promoting sustainable resource use, reducing greenhouse gas emissions, and enhancing ecosystem services. However, the adoption of CSA faces several challenges, including limited awareness, financial constraints, policy gaps, and socio-economic inequalities. The paper emphasizes the importance of integrated policies, capacity building, and community engagement in promoting CSA practices. Furthermore, it underscores the need for interdisciplinary collaboration among agricultural scientists, public health professionals, and policymakers to address climate-related health challenges effectively. CSA represents a promising pathway for achieving sustainable agriculture and resilient public health systems. Its widespread implementation can significantly contribute to global efforts aimed at combating climate change and improving population health outcomes.

**Keywords:** *Climate-smart agriculture, public health resilience, climate change, food security, sustainable agriculture.*

## 1. Introduction

Climate change is one of the most pressing global challenges of the 21st century, with far-reaching impacts on agriculture, ecosystems, and human health (2,3). Rising temperatures, erratic rainfall patterns, and an increased frequency of extreme weather events such as droughts, floods, and heatwaves are disrupting agricultural systems and threatening food security worldwide (3,4). These environmental changes have direct and indirect consequences for public health, including increased prevalence of malnutrition, heat-related illnesses, and the spread of infectious diseases (2,9). In this context, the need for sustainable and adaptive agricultural strategies has become more critical than ever (1). Climate-Smart Agriculture (CSA) has emerged as a comprehensive approach to address the dual challenges of food security and climate change (1). Introduced by the Food and Agriculture Organization (FAO), CSA aims to achieve three main objectives: sustainably increasing agricultural productivity, enhancing resilience to climate change, and reducing greenhouse gas emissions wherever possible (1,5). By integrating these objectives, CSA provides a framework for transforming agricultural systems in a way that supports both environmental sustainability and human health (6). The relationship between agriculture and public health is deeply interconnected. Agricultural practices influence the availability, accessibility, and quality of food, which are key determinants of nutritional health (4,6). At the same time, agricultural activities can impact environmental conditions, including air and water quality, which directly affect human health (9). Climate change further complicates this relationship by altering disease patterns, increasing the risk of foodborne and waterborne illnesses, and exacerbating existing health inequalities (2,17). One of the critical pathways through which climate change affects public health is food insecurity. Changes in crop yields and food production can lead to reduced food availability and increased prices, making it difficult for vulnerable populations to access adequate nutrition (4,10). This can result in malnutrition, particularly among children and pregnant women, and increase susceptibility to diseases (2). CSA practices, such as the use of drought-tolerant crop varieties and improved soil management techniques, can help stabilize food production and enhance nutritional outcomes (15), climate change also influences the spread of vector-borne diseases such as malaria, dengue fever, and Zika virus (17). Changes in temperature and precipitation patterns can expand the habitats of disease vectors, increasing the risk of outbreaks in new regions (2,17). Agricultural practices that involve water management, such as irrigation systems,

can either exacerbate or mitigate these risks depending on how they are implemented (11). CSA promotes efficient water use and proper management practices that reduce the likelihood of vector breeding and disease transmission (11). Furthermore, climate change contributes to increased exposure to extreme heat, which can have serious health implications, particularly for agricultural workers who spend long hours outdoors (2). Heat stress can lead to dehydration, heat exhaustion, and even death in severe cases. CSA practices, such as agroforestry and improved land management, can help create microclimates that reduce heat exposure and improve working conditions for farmers (8). Environmental degradation associated with conventional agricultural practices, including deforestation, soil erosion, and excessive use of chemical inputs, further exacerbates climate change and its health impacts (5,12). CSA encourages sustainable land use practices that protect natural resources and enhance ecosystem services, such as carbon sequestration, water filtration, and biodiversity conservation (12,16). These ecosystem services play a vital role in maintaining environmental health and supporting human well-being (9). Despite its potential benefits, the adoption of CSA is not without challenges. Many farmers, particularly in developing countries, face barriers such as limited access to information, financial resources, and technical support (11,19). Additionally, policy frameworks and institutional support systems are often inadequate to promote widespread adoption of CSA practices (19). Addressing these challenges requires coordinated efforts at local, national, and global levels (19). CSA represents a promising approach to addressing the interconnected challenges of climate change, agriculture, and public health (1). By promoting sustainable and resilient agricultural practices, CSA can contribute to improved health outcomes and enhanced resilience of communities in the face of climate change (2).

### 1.1 Food Security and Nutritional Health

Climate-Smart Agriculture (CSA) plays a fundamental role in strengthening food security and improving nutritional health by addressing the interconnected challenges of climate change, agricultural productivity, and human well-being. Food security encompasses not only the availability of food but also access, utilization, and stability over time. CSA contributes to all these dimensions by promoting agricultural practices that enhance productivity while maintaining environmental sustainability. In the context of a changing climate, where extreme weather events such as droughts, floods, and temperature fluctuations are becoming more frequent, CSA provides adaptive strate-

**Table 1.** Climate-Smart Agricultural Practices and Their Public Health Benefits

CSA Practice	Description	Public Health Benefits
Conservation Agriculture	Minimum soil disturbance, crop rotation, and residue retention	Improves soil health, enhances food quality, reduces exposure to harmful chemicals
Agroforestry	Integration of trees with crops and livestock	Reduces heat stress, improves air quality, enhances nutrition through diverse food
Climate-Resilient Crops	Use of drought, flood, and pest-resistant crop varieties	Ensures food security, reduces risk of malnutrition
Efficient Irrigation Systems	Drip and sprinkler irrigation techniques	Reduces waterborne diseases, prevents water contamination
Integrated Pest Management	Use of biological and cultural methods to control pests	Minimizes pesticide exposure, reduces health risks
Organic Farming	Avoidance of synthetic fertilizers and pesticides	Produces safer food, reduces chemical-related health hazards
Crop Diversification	Growing multiple crops in a system	Improves dietary diversity and nutritional intake
Soil Health Management	Use of organic manure, compost, and biofertilizers	Enhances nutrient-rich food production, reduces soil contamination
Climate Change Factor	Impact on Agriculture	CSA Response Strategy

**Table 2.** Climate Change Impacts, Agricultural Responses, and Health Outcomes

Climate Change Factor	Impact on Agriculture	CSA Response Strategy	Public Health Outcome
Rising Temperatures	Reduced crop yields, heat stress on livestock	Agroforestry, heat-tolerant crops	Reduced heat-related illnesses, improved productivity
Erratic Rainfall	Crop failure, water scarcity	Rainwater harvesting, drought-resistant crops	Improved food security, reduced malnutrition
Flooding	Soil erosion, crop damage	Improved drainage, flood-resistant crops	Reduced waterborne diseases
Drought	Reduced agricultural productivity	Efficient irrigation systems	Prevention of food shortages and undernutrition
Increased Pests/Diseases	Crop losses, increased pesticide use	Integrated pest management	Reduced chemical exposure and related health issues
Water Contamination	Pollution from agricultural runoff	Sustainable fertilizer use, water management	Reduced gastrointestinal and chronic diseases
Loss of Biodiversity	Reduced ecosystem resilience	Agroecology and diversification	Improved nutrition and ecosystem stability
Extreme Weather Events	Disruption of farming systems	Climate adaptation planning	Enhanced community resilience and reduced vulnerability

gies that ensure consistent crop production and reduce the vulnerability of farming systems. One of the key approaches within CSA is crop diversification, which involves cultivating a variety of crops rather than relying on a single species. This practice enhances resilience

against climate-related risks and ensures a more balanced and diverse food supply. Different crops respond differently to environmental stresses, so diversification reduces the likelihood of total crop failure. Additionally, it contributes to improved dietary diversity,

which is essential for addressing micronutrient deficiencies and promoting overall health. The inclusion of nutrient-rich crops such as legumes, fruits, and vegetables in farming systems ensures that populations have access to essential vitamins, minerals, and proteins. Improved seed varieties are another important component of CSA. These varieties are often developed to be drought-tolerant, heat-resistant, or pest-resistant, enabling them to perform better under adverse climatic conditions. The use of such seeds enhances crop yields and ensures stable food production even in challenging environments. This stability is critical for maintaining food availability and preventing food shortages, particularly in regions that are highly vulnerable to climate change. Soil fertility management is also central to CSA practices. Techniques such as organic fertilization, composting, and conservation tillage improve soil health by increasing organic matter content and enhancing nutrient availability. Healthy soils not only support higher crop yields but also improve the nutritional quality of food. For example, nutrient-rich soils contribute to higher concentrations of essential elements in crops, which directly benefit human health. CSA also promotes sustainable food systems by reducing post-harvest losses and improving food distribution. Post-harvest losses, which occur due to inadequate storage, transportation, and processing facilities, significantly reduce the amount of food available for consumption. By introducing improved storage technologies and efficient supply chain management, CSA ensures that more food reaches consumers in good condition. This is particularly important in developing regions where post-harvest losses are high. Furthermore, CSA integrates nutrition-sensitive agriculture, which explicitly links agricultural practices with nutritional outcomes. This approach emphasizes the production of diverse and nutrient-dense foods while considering the nutritional needs of different population groups. By aligning agricultural production with nutritional goals, CSA contributes to the reduction of malnutrition, including both undernutrition and overnutrition. CSA provides a comprehensive framework for improving food security and nutritional health. Through practices such as crop diversification, improved seed use, soil management, and efficient food systems, it ensures the availability of nutritious food while enhancing resilience to climate change. These contributions are essential for achieving sustainable development and improving public health outcomes.

## 1.2 Climate Change and Disease Dynamics

Climate change has profound implications for disease dynamics, influencing the distribution, transmis-

sion, and prevalence of various infectious and non-communicable diseases. Changes in temperature, precipitation patterns, and extreme weather events create favorable conditions for the proliferation of pathogens and vectors, thereby increasing the risk of disease outbreaks. Climate-Smart Agriculture (CSA) plays a critical role in mitigating these risks by promoting sustainable land and water management practices that enhance ecosystem stability and reduce environmental factors contributing to disease transmission. One of the most significant impacts of climate change on health is the increased prevalence of vector-borne diseases such as malaria, dengue, and chikungunya. Warmer temperatures and increased humidity create ideal conditions for the breeding and survival of disease-carrying vectors such as mosquitoes. Changes in rainfall patterns can also lead to the formation of stagnant water bodies, which serve as breeding sites for these vectors. CSA practices, particularly those related to water management, can help address this issue. For example, efficient irrigation systems and proper drainage mechanisms prevent water stagnation, thereby reducing the breeding grounds for mosquitoes and lowering the incidence of vector-borne diseases. In addition to vector-borne diseases, climate change also influences the spread of waterborne diseases. Increased flooding and extreme rainfall events can contaminate water sources with pathogens, leading to outbreaks of diseases such as cholera and diarrhea. CSA approaches that emphasize water conservation, sanitation, and sustainable land management help protect water quality and reduce the risk of contamination. By maintaining clean water sources, these practices contribute to improved public health outcomes. Zoonotic diseases, which are transmitted from animals to humans, are another area of concern in the context of climate change. Environmental degradation, deforestation, and habitat fragmentation increase human-wildlife interactions, creating opportunities for the transmission of pathogens. CSA promotes sustainable land use practices such as agroforestry and biodiversity conservation, which help maintain ecological balance and reduce the likelihood of such interactions. By preserving natural habitats and supporting biodiversity, CSA reduces the risk of zoonotic disease emergence. Furthermore, climate change can weaken agricultural systems, leading to food insecurity and malnutrition, which in turn increase susceptibility to diseases. CSA enhances the resilience of agricultural systems, ensuring stable food production and improving nutritional status. Well-nourished populations are better equipped to resist infections and recover from illnesses, highlighting the indirect health benefits of CSA. CSA also contributes to

reducing the spread of plant diseases, which can have cascading effects on food security and human health. Healthy crops are less susceptible to diseases, and sustainable farming practices reduce the need for chemical inputs that can have adverse health effects. By promoting integrated pest and disease management, CSA ensures safer and more sustainable agricultural systems. CSA provides a holistic approach to addressing the complex relationship between climate change and disease dynamics. Through improved water management, sustainable land use, and enhanced agricultural resilience, it helps reduce the environmental drivers of disease transmission while promoting better health outcomes.

### **1.3 Environmental Sustainability and Health Outcomes**

Environmental sustainability is a central pillar of Climate-Smart Agriculture, with far-reaching implications for human health and well-being. The degradation of natural resources, including soil, water, and air, poses significant threats to both environmental and public health. CSA addresses these challenges by promoting agricultural practices that conserve natural resources, reduce pollution, and enhance ecosystem services, thereby creating a healthier environment for human populations. One of the key strategies within CSA is agroforestry, which involves the integration of trees and shrubs into agricultural landscapes. Agroforestry systems provide multiple environmental benefits, including improved soil fertility, enhanced biodiversity, and increased carbon sequestration. Trees act as natural filters, improving air quality by absorbing pollutants and releasing oxygen. They also help regulate microclimates, reducing temperature extremes and creating more favorable conditions for crop growth. These environmental improvements have direct health benefits, such as reduced respiratory problems and improved overall well-being. Conservation agriculture is another important component of CSA that contributes to environmental sustainability. Practices such as minimal soil disturbance, crop rotation, and permanent soil cover help maintain soil health and prevent erosion. Healthy soils are essential for sustainable food production, as they provide the nutrients necessary for crop growth. Additionally, improved soil structure enhances water infiltration and reduces runoff, preventing soil and water pollution. This contributes to cleaner water sources, which are crucial for preventing waterborne diseases. Organic farming practices within CSA further support environmental and health outcomes by reducing the use of synthetic chemicals. The excessive use of chemical fertilizers and pesticides

can lead to soil degradation, water contamination, and health risks for farmers and consumers. By promoting the use of organic inputs and natural pest control methods, CSA reduces chemical exposure and supports safer food production systems. This is particularly important for protecting vulnerable populations, including children and agricultural workers. CSA also plays a significant role in mitigating climate change, which has direct and indirect effects on health. By reducing greenhouse gas emissions and enhancing carbon sequestration, CSA helps limit global warming and its associated health risks. Climate change is linked to a range of health issues, including heat stress, respiratory diseases, and the spread of infectious diseases. By addressing the root causes of climate change, CSA contributes to the prevention of these health challenges. Moreover, CSA enhances ecosystem services such as pollination, water purification, and nutrient cycling. These services are essential for maintaining environmental balance and supporting agricultural productivity. Healthy ecosystems provide clean air and water, which are fundamental to human health, environmental sustainability within CSA is closely linked to improved health outcomes. By conserving natural resources, reducing pollution, and mitigating climate change, CSA creates a healthier environment that supports both agricultural productivity and human well-being.

### **1.4 Socio-Economic Resilience and Community Health**

Socio-economic resilience is a critical dimension of Climate-Smart Agriculture, as it directly influences the capacity of individuals and communities to adapt to climate-related challenges and maintain their health and well-being. CSA enhances resilience by improving agricultural productivity, stabilizing incomes, and promoting sustainable livelihoods, thereby reducing vulnerability to environmental and economic shocks. One of the primary ways in which CSA contributes to socio-economic resilience is by increasing farmers' income stability. Climate variability often leads to fluctuations in crop yields, which can result in financial instability for farmers. CSA practices, such as the use of climate-resilient crop varieties and efficient resource management, help ensure consistent production and reduce the risk of crop failure. Stable income allows farmers to invest in essential services such as healthcare, education, and nutrition, which are key determinants of overall well-being. CSA also promotes diversification of income sources, which is an important strategy for reducing economic risk. In addition to crop production, farmers can engage in activities such as livestock rear-

ing, agroforestry, and value-added processing. This diversification provides multiple streams of income, making households more resilient to market fluctuations and environmental shocks. Increased financial security enables families to access better healthcare and maintain a balanced diet, contributing to improved health outcomes. Community-based approaches are another important aspect of CSA. These approaches emphasize collective action, knowledge sharing, and capacity building among farmers and local communities. Through training programs, extension services, and farmer cooperatives, CSA promotes the dissemination of best practices and innovative technologies. This collective learning process enhances the ability of communities to adapt to changing conditions and implement sustainable agricultural practices. Social inclusion and equity are also important considerations within CSA frameworks. Vulnerable groups, including smallholder farmers, women, and marginalized communities, often face greater challenges in accessing resources and adapting to climate change. CSA initiatives that prioritize inclusivity help ensure that these groups benefit from improved agricultural practices and technologies. Empowering women farmers, for example, has been shown to improve household nutrition and health outcomes, as women often play a central role in food production and family care. Furthermore, CSA contributes to improved community health by addressing the social determinants of health. Access to sufficient food, clean water, and a stable income are essential for maintaining good health. By enhancing agricultural productivity and environmental sustainability, CSA helps create conditions that support these basic needs, resilient communities are better equipped to respond to and recover from climate-related disasters such as droughts and floods. CSA practices that improve soil health, water management, and ecosystem stability reduce the impact of such events, protecting both livelihoods and health, CSA strengthens socio-economic resilience by improving livelihoods, promoting community engagement, and addressing inequalities. These factors collectively contribute to better health outcomes and more sustainable development, highlighting the importance of CSA in building resilient and healthy communities.

## 2. Conclusion

Climate-Smart Agriculture represents a transformative approach to addressing the interconnected challenges of climate change, food security, and public health (1). By integrating adaptation, mitigation, and productivity goals, CSA offers a comprehensive framework for building resilient agricultural systems and healthier com-

munities (5). However, the successful implementation of CSA requires overcoming various barriers, including limited awareness, financial constraints, and policy gaps (19). Strengthening institutional support, enhancing farmer education, and promoting inclusive policies are critical steps toward scaling up CSA practices (11). CSA has the potential to significantly enhance public health resilience in the face of climate change (2). Its widespread adoption can contribute to sustainable development goals by ensuring food security, protecting environmental resources, and improving health outcomes globally (3,10).

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