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Climate Change Impacts on Agroecosystems, Food Security and Community Well-being in Punjab, Pakistan: A Systematic Review

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Abstract

The food system of Pakistan, especially in Punjab, is changing due to the climate change phenomenon, and it is impacting the country's crop output. The present review is based on a critical study of findings from 25-plus research papers and policy reports from Google Scholar, Web of Science, Research Gate, and JASTOR, covering the period of 2010 to 2025. Studies were selected based on their relevance to climate change impacts, food security, agro-ecosystem vulnerability, and adaptation strategies, with a specific focus on Punjab Province. Studies show that climate stressors, including droughts, floods, and unpredictable rainfall, can lower rice production by more than 15% during flood seasons and wheat yields by up to 12% during dry years. Following climate shocks, household food costs rise by 20–30%, making rural poverty worse. Due to institutional and financial limitations, smallholders who make up more than 80% of farmers continue to be disproportionately susceptible. Research further evaluates sustainable ecosystem pathways, including climate –smart agriculture, ecosystem-based adaptations, and regenerative soil-water management, which shows quantifiable advantages such as 15–20% greater net returns among adopters. However, its adoption is limited due to institutional, financial, and informational barriers. These findings highlight that addressing food insecurity in Punjab requires integrating technological innovation, inclusive governance, and coordinated policy reforms across the agriculture, climate, and health sectors.

Keywords

Climate Change, Food Security, Climate-Smart Agriculture, Ecosystem-Based Adaptation, Community Resilience

Introduction

Climate change poses a serious threat to sustainable living and community well-being by changing rainfall patterns, temperature trends, and the frequency of extreme occurrences. Both human

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systems and natural ecosystems are directly impacted by these changes, especially food production and rural livelihoods (Raj et al., 2022). According to the IPCC's 2023 synthesis report, concerns about food security, nutrition, and socioeconomic stability are increasing globally as a result of climate-related challenges on agriculture, especially in underdeveloped nations with very little capacity for adaptation. Population expansion, resource depletion, and climate variability are putting more and more pressure on food systems in emerging nations. Aziz (2025) discussed that food insecurity is a result of decreased agricultural yields, broken supply chains, and rising food costs, which also have an adverse effect on community well-being by increasing poverty, hunger, and livelihood instability. Naz et al., (2024) stated that climate change poses a direct threat to human well-being and food supply since agriculture continues to be the main source of income for a significant portion of rural populations. Recent studies show that food production in South Asia could drop by 10-25% by the middle of the century if no adaptation measures are taken, with key irrigated areas like Punjab being at higher risk (Syed et al., 2022).

Pakistan’s position, reliance on agriculture, and vulnerability to heatwaves, droughts, and floods make it one of the most climate-vulnerable nations. National food security is seriously threatened by climate change, which has already had an impact on rural livelihoods, water resources, and agricultural production (Aitzaz et al., 2024). These impacts are particularly evident in Punjab Province, which provides over 83% cotton, 80% wheat, 97% fine aromatic rice, 63% sugarcane, and 51% maize to the country's food supply, making it a significant contributor to the agricultural economy (Latif et al., 2024).

Punjab offers a meaningful case study for examining climate change impacts through a sustainable ecosystem perspective. The province supports extensive irrigated agriculture under the Indus Basin system but faces increasing risks from water scarcity, soil degradation, and extreme weather events (Shirazi, 2020). Empirical studies report declining yields of major crops and heightened vulnerability among farming communities due to climate variability (Cheema and Sharoon, 2025). Despite increasing research on climate change in South Asia, comprehensive studies that link agro-ecosystem fragility, food security, and community well-being within the specific context of Punjab remain limited (Nadeem et al., 2022; Mumtaz et al., 2019). This review addresses this gap by synthesizing empirical and policy-based evidence to identify sustainable adaptation pathways for Punjab Province. Given its central role in food production, climate-induced disruptions in Punjab have wide-ranging implications for national food security and community well-being. The review aims to: (i) Assess climate change impacts on agricultural productivity in Punjab; (ii) Examine implications for food security and community well-being; (iii) Identify sustainable ecosystem-based strategies that enhance resilience.

Methodology

This study employed a systematic literature review methodology, synthesizing peer-reviewed articles, policy reports, and empirical studies published between 2010 and 2025. Literature was retrieved from Google Scholar, Web of Science, Research Gate, and JSTOR using keywords such as "climate change AND Punjab, Pakistan," "food security AND climate change AND Pakistan," "climate-smart agriculture Pakistan," and "ecosystem-based adaptation Punjab." Studies were included if they focused on Pakistan or Punjab Province and addressed climate change impacts,

food security, agro-ecosystem vulnerability, or adaptation strategies. Studies unrelated to agricultural or food systems outside South Asia, or lacking peer review were excluded. A total of 25+ studies were retained for the final synthesis.

Results and Discussion

Interconnected Systems: Climate, Food, and Human Well-Being

Climate change is undermining food systems through rising temperatures, altered rainfall, and extreme events, particularly in agrarian regions such as Punjab, Pakistan (Khan et al., 2016; Saleem et al., 2025). As agriculture contributes nearly 24% to Pakistan's GDP and 37.4% of employment, climatic shocks such as the 2022 monsoon floods have significantly reduced crop yields and disrupted food supply chains, disproportionately affecting smallholder farmers (Saleem et al., 2025). These impacts translate into declining household incomes, food insecurity, and adverse health outcomes, including malnutrition and psychological stress (Hanif et al., 2010). While Lin (2011) emphasizes crop diversification as a primary resilience strategy, Hanif et al. (2010) demonstrates that ecological solutions alone are not sufficient without parallel socioeconomic interventions. Therefore, climate-smart agriculture and inclusive governance are equally essential for community well-being.

Figure 1. Climate, food systems, and human well-being are connected: changes in one affect the others, influencing nutrition, health, and resilience. Adapted from Raj et al. (2022), Naz et al. (2024), and Saleem et al. (2025). Created using Canva.

The interdependence of food production, climatic systems, and human well-being is depicted in Figure 1. The graphic illustrates how climate stresses, including droughts, floods, and rising temperatures, directly lower agricultural productivity, which has an impact on household income, food access, and nutritional outcomes (Raj et al., 2022). It also shows how weaker food systems make people more susceptible to poverty and health problems, which feeds back into a cycle that makes communities less resilient overall (Naz et al., 2024; Saleem et al., 2025). This interrelated approach highlights that climate change necessitates integrated policy solutions because it is not only an environmental problem but also a socioeconomic and public health issue

Changing Climate and Fragile Agro-Ecosystems in Punjab

With rising temperatures, unpredictable rainfall, water scarcity, and harsh weather lowering crop yields and soil fertility, Punjab's agriculture is extremely sensitive to climate change (Nadeem et al., 2022). While Nadeem et al. (2022) highlight physical stressors like heat and water scarcity as primary drivers of agro-ecosystem fragility, Mumtaz et al. (2019)'s study shows that institutional failures enhance these impacts beyond what climate variability would cause, suggesting that vulnerability in Punjab is as much a governance challenge as an environmental one. According to farmers, awareness of climate stress is growing, but adaptation is hampered by a lack of resources, underscoring the critical need for integrated resilience planning (Nadeem et al., 2024). The major climate stressors, agro-ecosystem impacts, and farmer responses are summarized in Table 1 (see Table 1)

Table 1. Climate Stressors and Farmer Responses in Punjab.

Climate Stressor	Impact on Agro-Ecosystem	Farmer Response	Source
Rising temperatures	Heat stress on wheat and rice yields	Shift sowing dates, heat-tolerant varieties	Nadeem et al., (2022)
Erratic rainfall	Floods & droughts damaging soil fertility	Crop diversification, rainwater harvesting	Mumtaz et al., (2019)
Water scarcity	Declining irrigation capacity	Efficient irrigation, canal water management	Nadeem et al., (2022)
Extreme events	Livelihood insecurity and crop failure	Informal coping strategies, migration	Nadeem et al., (2024)

These findings indicate that sustainable agricultural practices are already delivering measurable resilience benefits in Punjab; however, Nadeem et al. (2022) caution that uneven adoption persists due to institutional, financial, and knowledge barriers. This finding is consistent with Mumtaz et al., (2019), who emphasize that without structural reforms, farmer-level coping strategies alone cannot ensure province-wide food security.

Food Security at Risk: Evidence from Punjab's Agricultural Landscape

Punjab's primary crops, especially wheat and rice, which together provide more than 70% of Pakistan's basic food supply, are being harmed by climate-induced stress, putting the region's food security at greater danger (Nadeem et al., 2022). Rising temperature and unpredictable rainfall have decreased rice productivity 15% during flood seasons and wheat yields by up to 12% in drought years (Khetran and Salik, 2024). While (Khetran and Salik 2024) confirm rising household food expenditures of 20-30% following climate shocks, Usman et al., (2025) further emphasize

that rural communities observe governance failure as equally responsible for food insecurity as climate events themselves, pointing to a critical gap between policy design and ground-level implementation. Smallholder and marginal farming communities comprising over 80% of Punjab's farmers face heightened exposure due to limited adaptive capacity and financial buffers (Mumtaz et al., 2019; Naz et al., 2024).

Pathways to Sustainability: Ecosystem-Based and Community-Driven Solutions

In Punjab, Pakistan, where climate change has severely stressed agro-ecosystems and food security, ecosystem-based and community-driven approaches are being increasingly acknowledged as crucial routes to sustainability. Crop diversification, agroforestry, and integrated pest management are examples of ecosystem-based adaptation (EbA) techniques that have been demonstrated to increase ecological resilience while lowering vulnerability to climatic extremes (Nadeem et al., 2024). Farmers in Punjab report notable increases in household welfare and production when they implement climate-smart and regenerative agriculture techniques, such as conservation tillage, organic soil amendments, and precision irrigation. For instance, South Punjabi wheat farmers who adopted climate-smart strategies had a 15–20% improvement in net earnings when compared to traditional methods (Bibi, 2025).

Due to inadequacies in Punjab's irrigation system, which loses about half of the water available, sustainable soil and water management is still crucial. To stabilize yields and lessen resource depletion, interventions such as drip irrigation, rainwater collecting, and soil conservation practices are being pushed (Arshad and Abdulai, 2025). Crucially, local knowledge and community involvement are essential to the effectiveness of adaptation. Although there are still participation disparities among women and young people, Jabbar et al. (2023) discovered that collective action groups among smallholders in Punjab enhanced adaptive ability by combining resources, exchanging knowledge, and promoting social cohesion.

Promising practices from Punjab include wheat growers using regenerative soil techniques to increase productivity (Bibi, 2025), livestock farmers incorporating climate-smart agriculture to improve household welfare (Arshad and Abdulai, 2025), and grassroots cooperatives building resilience through shared adaptation strategies (Jabbar et al., 2023). However, Bibi (2025) reports measurable economic gains at the individual farm level, Arshad and Abdulai (2025) highlight that broader welfare improvements remain constrained by financial and institutional barriers. This confirms that sustainability in Punjab requires not only technological innovation but also inclusive governance and equitable participation. Key sustainable agricultural practices and their outcomes are presented in Table 2 (see Table 2).

Table 2. Sustainable Agricultural Practices Supporting Climate Resilience in Punjab.

Sustainable Practice	Evidence from Punjab	Key outcomes	Source
Climate-smart wheat cultivation	Adoption of improved varieties and precision irrigation	15–20% higher net returns	Mehmood et al., 2023
Conservation tillage	Improved soil moisture retention	Yield stability under heat stress	Imran et al., 2018

Drip and precision irrigation	Pilot adoption in water-scarce districts	30–40% water savings	Zafar et al., 2020
Crop diversification	Shift from mono-cropping systems	Reduced climate risk	Hammad et al., 2024
Collective action groups	Farmer cooperatives	Improved adaptive capacity	Imran et al., 2018

Climate-smart wheat increases net returns by 15–20%, and conservation tillage and drip irrigation increase soil and water efficiency (Mehmood et al., 2023). These benefits of sustainable farming in Punjab are evident. However, because of high costs, financing limitations, and information gaps, adoption is inconsistent (Zafar et al., 2020). Training farmers, financial assistance, and inclusive governance are necessary for scaling up.

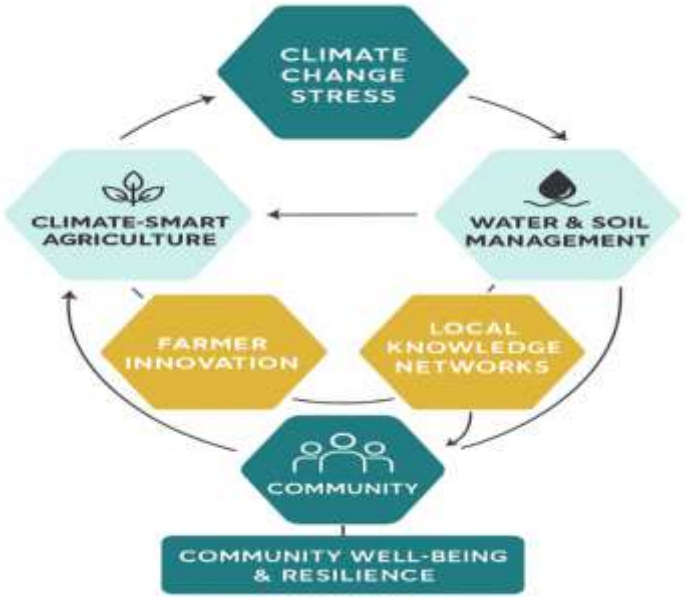

Figure 2. Sustainable pathways linking climate stress to community resilience in Punjab. Original diagram developed by the author using Canva, based on Nadeem, et al. (2024), Jabbar et al., (2023), and Bibi (2025).

Figure 2 illustrates how sustainable practices help communities adapt to climate stress. It shows that combining ecosystem-based strategies with community participation strengthens long-term resilience (Nadeem et al., 2024; Jabbar et al., 2023).

Policy Integration and Governance Response for Food Security and Climate Resilience in Pakistan

Pakistan's food security issues require both robust supply chains and efficient policy implementation to survive climate stress. According to Afshar (2025), livestock supply chains which are essential to rural livelihoods remain extremely susceptible to climate shocks, but they can be strengthened by implementing climate-smart agriculture (CSA) techniques like better feed management, disease prevention, and adaptive breeding, improving household food security and

economic resilience. However, Mahmood et al. (2025) assess national plans for implementing food security and identify significant gaps between the design and implementation of policies, such as poor institutional coordination, little outreach to farmers, and insufficient monitoring systems. According to their results, Pakistan has created extensive frameworks for food security, but their efficacy is compromised by the lack of connectivity across the agricultural, health, and climatic sectors. All of these studies point to the necessity of coordinating CSA-driven adaptive practices with strong governance reforms to ensure that resilient supply chains are backed by cogent, well-executed policies that address social and ecological vulnerabilities.

Conclusion

Climate change significantly reduces wheat and rice yields in Punjab, leading to measurable food insecurity and economic instability at the household level. Smallholder farmers, who make up more than 80% of Punjab's farming population, remain disproportionately vulnerable due to limited adaptive capacity. Ecosystem-based adaptation and climate-smart agriculture offer measurable benefits, including 15–20% higher net returns; however, scalability remains constrained by institutional and financial barriers. To strengthen food security in Punjab, concrete recommendations are proposed at both institutional and policy levels. At the institutional level, provincial agricultural departments should establish dedicated subsidy programs targeting drip irrigation and heat-tolerant seed varieties for smallholder farmers, while restructuring extension services to deliver climate-smart agriculture training directly at the union council level. At the policy level, a cross-ministerial task force linking the Ministry of Agriculture, Ministry of Climate Change, and Ministry of Health should be formed to eliminate sectoral fragmentation in food security governance. Additionally, farmer cooperative programs should mandate gender-inclusive participation quotas to ensure that women and youth are integrated into adaptation planning and resource distribution.

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