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Climate Change Adaptation Strategies of Small Farmers: Challenges and Perspectives

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ABSTRACT

Climate change presents an unprecedented challenge to agricultural sustainability, food security, and the livelihood of rural populations worldwide. In India, where over 80% of farmers are small and marginal, limited adaptive capacity, economic constraints, and dependence on rain-fed agriculture exacerbate vulnerability to climate extremes. This review synthesizes global and Indian research on the impacts of climate change on smallholder agriculture, focusing on farmers' perceptions, adaptation strategies, gendered dimensions, and institutional roles. It integrates findings from 15 key studies conducted between 2017 and 2025, highlighting both progress and persisting gaps in adaptation efforts. The review underscores the need for integrated, participatory, and gender-responsive approaches to strengthen climate resilience at the grassroots level.

Keywords: Climate change, Adaptation, Smallholder farmers, Livelihood, Gender, Extension services, India, Climate-smart agriculture

INTRODUCTION

Agriculture remains the backbone of India's rural economy, contributing approximately 17.94 per cent to national GDP and employing 45.50 per cent of the workforce (MoSPI, 2023). The sector sustains over 70 per cent of rural households, the majority being small and marginal farmers. However, changing climatic conditions—rising temperatures, erratic rainfall, droughts, and floods-pose serious threats to productivity, food security, and livelihoods.

India's agricultural vulnerability stems from its high dependency on monsoon rainfall, low adaptive capacity, and limited access to technological and institutional resources (World Bank, 2023). These conditions necessitate urgent interventions to enhance climate literacy, strengthen adaptation strategies, and reduce risks for rural farming communities.

The Intergovernmental Panel on Climate Change (IPCC, 2014) defines climate change as long-term alterations in the mean and variability of climatic variables, typically lasting decades or more. The impacts are both global and local rising global temperatures, changing precipitation patterns, and increasing frequency of extreme events.

Agriculture contributes to climate change through greenhouse gas (GHG) emissions- methane from livestock and rice fields, nitrous oxide from fertilizers, and carbon dioxide from deforestation (NITI Aayog, 2025). Conversely, agriculture is highly vulnerable to these same changes, leading to yield reductions, pest infestations, and loss of soil fertility.

Impact of climate change on smallholder farmers:

Climate change has emerged as one of the most critical challenges to smallholder agriculture, particularly in developing economies such as India, where small and marginal farmers constitute the majority of the agricultural

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workforce. These farmers are especially vulnerable due to their heavy dependence on rainfall, limited access to irrigation facilities, constrained financial resources, and inadequate adaptive capacities (Birthal *et al.*, 2021; IPCC, 2022). Rising temperatures, erratic and unpredictable rainfall patterns, and an increasing frequency of extreme weather events have led to significant declines in crop productivity and overall agricultural output. Several studies have shown that temperature increases and rainfall variability directly reduce yields of major crops such as rice, wheat, and maize, thereby threatening household food security and income stability (Aggarwal and Mall, 2002; Lobell *et al.*, 2011; Birthal *et al.*, 2021).

Moreover, climate-induced shifts in temperature and humidity have altered pest and disease dynamics, leading to greater incidence of infestations and crop damage (FAO, 2016; Thornton *et al.,* 2018). This not only escalates input costs but also undermines the effectiveness of traditional farming practices. The resultant livelihood insecurity has been widely documented, as declining farm productivity and income losses push smallholders toward poverty traps and distress migration (Pandey *et al.*, 2018; Morton, 2007). Additionally, the impacts of climate change are not gender-neutral; women farmers often bear disproportionate burdens due to unequal access to land, credit, and extension services, coupled with their domestic and caregiving responsibilities (Assan *et al.*, 2018; Jost *et al.*, 2016).

Overall, climate change exacerbates existing socio-economic inequalities within the agricultural sector, making resilience-building measures—such as climate-smart agriculture, crop diversification, and institutional support-essential for safeguarding the livelihoods of small and marginal farmers (FAO, 2020; World Bank, 2021).

Gender Dimensions in Climate Adaptation:

Gender inequities play a critical role in shaping the adaptive capacity of farming households to climate change. Although women constitute a substantial share of the agricultural labor force, their ability to adapt is often constrained by systemic inequalities in access to land ownership, agricultural extension services, credit, and decision-making power (FAO, 2016; Meinzen-Dick *et al.,* 2019). Studies have consistently shown that these structural barriers limit women's participation in climate adaptation initiatives and reduce the overall resilience of rural communities. Assan *et al.* (2018) and Kurbetta (2024) reported that women farmers, due to socio-cultural and economic constraints, often rely more on informal coping mechanisms—such as strengthening social networks, diversifying household income, and reallocating domestic resources—while men are more likely to adopt farm-level technological or market-based adaptation strategies. Research across South Asia further emphasizes that gender empowerment through access to education, financial inclusion, and leadership opportunities enhances adaptive capacity and promotes equitable resilience to climatic shocks (Aryal *et al.,* 2021; Singh *et al.*, 2020; Jost *et al.,* 2016).

Moreover, studies from sub-Saharan Africa and South Asia demonstrate that gender-responsive adaptation policies—such as women's participation in farmer field schools, access to climate information services, and involvement in community-based natural resource management—lead to improved agricultural outcomes and long-term sustainability (Vincent *et al.*, 2017; Alam *et al.,* 2017; Doss *et al.*, 2018). The Intergovernmental Panel on Climate Change (IPCC, 2022) also underscores that addressing gender disparities is essential for achieving inclusive climate resilience. Therefore, mainstreaming gender perspectives in agricultural policy, technology dissemination, and rural development programs is crucial to enhancing the adaptive capacity of both women and men smallholders.

Impacts on Allied Sectors:

Livestock and Fisheries under Climate Change:

Climate change poses severe threats to both livestock and fisheries, sectors that form the backbone of rural livelihoods and nutritional security in many developing economies. In the livestock sector, rising temperatures and increased frequency of heatwaves have been associated with heat stress, leading to significant declines in milk yield, reduced reproductive efficiency, and elevated susceptibility to diseases (Ghasura *et al.*, 2024; Rojas-Downing *et al.*, 2017). Heat stress disrupts metabolic functions and hormonal balance in dairy animals, resulting in decreased conception rates and longer calving intervals (Nardone *et al.,* 2010; Bernabucci *et al.,* 2014). Additionally, changing rainfall patterns and prolonged dry spells exacerbate the scarcity of feed and fodder, driving up production costs and reducing profit margins, particularly for smallholder dairy farmers with limited adaptive capacity (Shantharaju *et*

al., 2024; Thornton *et al.,* 2015). Water scarcity also directly affects animal health and productivity, further intensifying economic vulnerability (Sejian *et al.*, 2018).

Similarly, the fisheries sector faces multiple climate-induced stressors. Rising water temperatures, ocean acidification, and altered hydrological cycles significantly affect fish physiology, breeding cycles, and migratory patterns (Wang *et al.,* 2023; FAO, 2022). Inland and coastal fisheries are witnessing shifts in species composition and distribution, with tropical species moving toward cooler waters, disrupting local fishing practices and livelihoods (Cheung *et al*., 2010; Pörtner *et al.*, 2021). Coastal ecosystems such as mangroves and coral reefs, which serve as critical breeding and nursery habitats, are also under threat from sea-level rise and salinity intrusion (Barange *et al.*, 2018). Post-harvest challenges, including spoilage risks due to higher ambient temperatures and unreliable energy access for cold storage, further compound the socio-economic impacts (Islam *et al.*, 2020). These combined effects highlight the urgent need for climate-resilient livestock management practices, sustainable aquaculture systems, and adaptive livelihood strategies to safeguard food security and rural incomes in the face of accelerating climate change.

Adaptation and Mitigation Strategies:

Farmers adopt a variety of adaptation measures to reduce risks:

- **Crop diversification and mixed farming systems** (Paramesh *et al.,* 2022).
- **Climate-smart agriculture (CSA)** practices—conservation tillage, precision irrigation, integrated nutrient management (Kurbetta *et al.*, 2020; Aryal *et al.,* 2020).
- **Agroforestry and soil management** for carbon sequestration (FAO, 2016).
- **Livelihood diversification** through livestock and non-farm income sources (Patel *et al.,* 2023).
- **Use of indigenous knowledge and early warning systems** (Pandey *et al*., 2018).

Mitigation strategies complement adaptation through efficient input use, reduced emissions, and renewable energy adoption in farming operations.

Role of Agricultural Extension in Climate Change Adaptation:

Agricultural extension plays a crucial role in bridging the gap between scientific knowledge and on-farm application, especially in the context of climate change adaptation and resilience building among smallholder farmers. Extension systems serve as key channels for disseminating climate information, promoting adaptive and sustainable agricultural practices, and enhancing farmers' decision-making capacity (Priya *et al.*, 2025; Davis and Sulaiman, 2014). Traditional approaches are increasingly being complemented by Information and Communication Technology (ICT)-based tools such as mobile advisories, interactive voice response systems, climate dashboards, and digital weather forecasting platforms that provide timely and location-specific information to farmers (Mittal and Mehar, 2016; Aker, 2011). Farmer Field Schools (FFS) and participatory learning models have also proven effective in improving farmers' understanding of climate risks, pest management, and resource conservation practices (Friis-Hansen and Duveskog, 2020).

However, several challenges limit the effectiveness of extension systems in addressing climate adaptation needs. In many developing regions, extension personnel face constraints such as inadequate training on climate-smart agriculture, limited operational funding, and weak institutional coordination across research, meteorological, and development agencies (Anderson and Feder, 2007; Sulaiman and Davis, 2012). Moreover, gender and social disparities often restrict women and marginalized farmers' access to extension services, reducing equitable participation in adaptation initiatives (Ragasa *et al.,* 2013; World Bank, 2021). Strengthening the capacity of extension workers through climate literacy programs, integrating ICT tools with local knowledge systems, and fostering multi-stakeholder collaboration can significantly improve the responsiveness and inclusiveness of agricultural extension under changing climatic conditions (FAO, 2020; Mbo'o-Tchouawou and Colverson, 2014).

Major Challenges:

- **Economic constraints:** Lack of credit, insurance, and financial inclusion.
- **Information gaps:** Limited access to localized weather forecasts and adaptation advisories.
- **Institutional fragmentation:** Poor coordination between research, extension, and policy bodies.
- **Gender disparity:** Unequal access to resources and decision-making power.
- **Technological barriers:** Low adoption of CSA due to knowledge and affordability gaps.

Table 1 : Review of Major Research Studies

Study	Location/Focus	Major Findings
Assan *et al.* (2018)	Ghana	Gendered adaptation patterns; men adopt farm-based interventions, women rely on social coping mechanisms.
Pandey *et al.* (2018)	Western Himalayas, India	Identified socio-economic and ecological barriers; adaptation hindered by lack of resources and awareness.
Kurbetta *et al.* (2020)	Karnataka	Farmers had moderate awareness of CSA; adoption constrained by cost and credit access.
Khatri-Chhetri *et al.* (2020)	India and Nepal	CSA adoption linked to education, farm size, and institutional support.
Paramesh *et al.* (2022)	India	Integrated farming enhances resilience; barriers include financial and technical limitations.
Aryal *et al.* (2021)	South Asia	Climate-resilient technologies improve productivity; institutional linkages essential for adoption.
Patel *et al.* (2023)	India	Farmers' adaptation motivated by livelihood security; non-adopters cite lack of finance and knowledge.
Ghasura *et al.* (2024)	Gujarat	Dairy adaptation correlated with education and herd size; non-adoption due to cost and information gaps.
Shantharaju *et al.* (2024)	South India	Dairy farmers report heat stress and feed shortages; need for risk management policies.
Kurbetta (2024)	Karnataka	Farm women's awareness varies by agro-climatic zone; recommends gender-responsive training.
Priya *et al.* (2025)	India	Highlights role of extension and ICT tools in strengthening climate literacy.
Sarkar and Padaria (2021)	Eastern India	Farmers' perceptions strongly influence adaptive behavior; extension contact enhances resilience.
Aggarwal *et al.* (2019)	India	Crop simulation models show yield losses of 10–40% under climate extremes; recommends regional adaptation planning.
Sapkota *et al.* (2020)	South Asia	Emphasizes policy coherence and cross-border research collaboration for effective adaptation.
Nguyen *et al.* (2017)	Vietnam	Economic incentives and social capital drive adaptation; highlights need for participatory approaches.

Way Forward:

Addressing the multifaceted challenges posed by climate change to smallholder agriculture requires a holistic and inclusive approach that combines technological, institutional, and social strategies. Strengthening climate literacy through community-based extension programs and ICT-enabled platforms can empower farmers with timely information on weather patterns, risk management, and adaptive practices. Integrating gender equity into climate adaptation and policy frameworks is equally essential to ensure that women farmers-who play a vital role in agricultural production-have equitable access to resources, training, and decision-making opportunities. The promotion of climate-smart technologies, such as drought-tolerant crop varieties, efficient irrigation systems, and renewable energy-based farm tools, should be supported through financial incentives, capacity-building initiatives, and extension support.

Furthermore, enhanced institutional collaboration between government departments, research institutions, NGOs, and private stakeholders can facilitate coordinated responses and ensure the effective dissemination of innovations at the grassroots level. Encouraging participatory research and fostering local innovations will help develop region-specific adaptation models that are contextually relevant and sustainable. Finally, improving access to affordable credit, crop insurance, and risk-transfer mechanisms can reduce farmers' vulnerability to climate shocks and economic losses. Collectively, these measures can strengthen the resilience of smallholder farming systems, promote sustainable livelihoods, and contribute to long-term climate adaptation and rural development.

Conclusion:

Climate change threatens the very foundation of India's agrarian economy. While small and marginal farmers continue to display remarkable resilience through traditional and adaptive practices, their efforts remain constrained by financial, institutional, and informational barriers. Building adaptive capacity requires an inclusive,

participatory, and multi-level approach that bridges scientific innovation and indigenous knowledge. Empowering farmers—especially women—with resources, skills, and decision-making power is essential for transitioning from vulnerability to resilience and ensuring the sustainability of India's rural economy.

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