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Exploring proximate determinants of farmers' adaptation measures to climate change: A comprehensive review

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Abstract
Climate change presents a critical global challenge, profoundly impacting agricultural development, livelihoods, and food security worldwide. This paper synthesizes researches to examine the escalating risks climate change, with projections indicating substantial crop yield reductions and heightened climate variability. Despite the implementation of diverse adaptation strategies by farmers, including altered cropping patterns and enhanced irrigation practices, significant gaps persist in effectively mitigating climate risks. Key determinants influencing farmers' adaptation decisions include access to financial resources, education, extension services, and socio-economic factors. The paper underscores the complex interplay of economic, social, and environmental dimensions in shaping adaptive capacity. Moving forward, there is a pressing need for enhanced research, policy support, and institutional frameworks to bolster agricultural resilience. This necessitates targeted interventions that provide farmers with timely climate information, promote sustainable farming practices, and ensure equitable access to resources. Collaborative efforts across local, national, and international levels are essential to scale up effective adaptation strategies and foster sustainable agricultural development in a changing climate, thereby safeguarding food security and livelihoods globally.

Keywords: Climate change, food security, adaptation measures and determinants of adaptation measures

Introduction

Climate change is a pressing global issue profoundly impacting development, particularly concerning livelihoods and food security worldwide. The unprecedented rise in greenhouse gas emissions has caused significant temperature increases and erratic rainfall patterns, which will increasingly affect agriculture and related industries [3]. As climate change continues unabated and global warming intensifies, farmers and rural communities worldwide face growing challenges. Agriculture has always been viewed as a high-risk sector, with farmers contending with multiple socio-economic and environmental factors [25]. The potential disruptions caused by climate change pose significant threats to major crops and overall food production systems [26], potentially leading to devastating impacts on farm production by the end of the 21st century [21].

Climate change represents a major challenge for agriculture in India, with forecasts indicating potential crop production losses ranging from 10% to 40% by 2100 in the absence of adaptation strategies [12]. India has already experienced a temperature rise of 0.68°C, with further warming anticipated, especially during the monsoon season [12]. These changes, coupled with rising climate variability and more frequent extreme weather events, will severely affect crop yields, livestock productivity, and the livelihoods of farmers [6, 13, 9].

Climate change poses significant challenges to Indian agriculture, including anticipated decreases in crop yields, crop damage from extreme weather events, and reduced nutritional quality of agricultural produce [6, 13, 9]. Without adaptation measures, rainfed rice yields are expected to decline by 20% in 2050 and 47% in 2080, while irrigated rice yields could decrease by 3.5% in 2050 and 5% in 2080 [13]. Wheat yields are projected to decline by 19.3% in 2050 and 40% in 2080, with considerable spatial and temporal variations [13]. Kharif maize yields are also forecasted to decrease by 18% in 2050 and 23% in 2080 [13].

To tackle these challenges, Indian farmers have implemented a variety of adaptation strategies, primarily through incremental and systemic changes [6]. These measures encompass adjustments in agricultural practices, such as shifting sowing and harvesting dates, adopting shorter-duration crop varieties, practicing inter-cropping and crop rotation, investing in irrigation, diversifying crops, and employing soil and water conservation techniques, as well as promoting agroforestry [10].

Adapting between crops includes cultivating rice, sorghum, and maize varieties that are more tolerant to heat, and shifting to wheat, which thrives better in cooler seasons [10]. Within the same crop, adaptations involve investing in irrigation to mitigate heat and drought stress, adjusting sowing dates to avoid heat impacts, using fertilizers or other agricultural inputs for heat management, and planting shade-providing trees to shield crops from high temperatures [10].

The Government of India has initiated various efforts to bolster climate change adaptation in agriculture. The National Mission for Sustainable Agriculture (NMSA) seeks

to develop and execute strategies to enhance the resilience of Indian agriculture to climate change [13]. Launched in 2011, the National Innovations in Climate Resilient Agriculture (NICRA) project focuses on advancing and advocating for climate-resilient technologies in susceptible regions [13].

At the state level, the Climate Change Adaptation in Rural Areas of India (CCA-RAI) project, funded by the German government, has aided 16 states and 2 union territories in formulating State Action Plans on Climate Change (SAPCC) [14]. These plans incorporate climate change considerations into policies, strategies, and initiatives, thereby enhancing adaptive capabilities at the grassroots level [14].

Despite these initiatives, there are substantial gaps in understanding future climate trends at more detailed levels, evaluating the impacts of climate change, and formulating efficient adaptation strategies [9]. There is a pressing need for coordinated research efforts to bolster the resilience and diminish the vulnerability of Indian agriculture to climate change across local, regional, and national contexts [9]. Encouraging collaboration between developed and developing nations, alongside adequate financial support, is crucial for advancing and transferring climate-smart technologies [9]. Equally important is the socio-psychological empowerment of farmers, coupled with enhancing their knowledge and skills in adapting to climate change [9].

In summary, Indian agriculture faces significant challenges from climate change, yet farmers have implemented diverse adaptation measures. Nevertheless, further research, policy backing, and capacity building are essential to strengthen the resilience of the agricultural sector. Bridging knowledge deficiencies and scaling up adaptation strategies will be crucial for maintaining agricultural productivity and ensuring food security amidst shifting climate conditions.

Reviewing Determinants of Farmers' Adaptation Measures to Climate Change: Insights from Multiple Reviews

Maddison (2007) [19] in a study titled "The perception of and adaptation to climate change in Africa," Heckman's sample selectivity probit model was employed to analyze the factors influencing climate change adaptation strategies. The findings revealed that greater farming experience heightened the probability of recognizing climate change. Moreover, education significantly impacted the selection of adaptation measures. Critical determinants for a farmer's adaptation to climate change encompassed access to extension services, proximity to markets, and policy implications.

These results underscore the importance of support systems and educational initiatives in enhancing farmers' resilience to climate change. Additionally, the study suggests that policies and accessible market infrastructure are vital for empowering farmers to effectively adapt to evolving climate conditions.

Deressa et al. (2008) [8] in the study titled "Analysis of the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile Basin of Ethiopia," utilized a logit model to identify key factors influencing farmers' awareness and adaptation strategies.

The study found that household wealth, along with income from both farm and non-farm sources, and livestock ownership significantly increased the likelihood of recognizing climate change and implementing adaptation methods.

These findings suggest that economic stability and diverse income sources play crucial roles in enabling farmers to perceive climate changes and adopt effective adaptation strategies. Furthermore, enhancing livestock assets and providing financial support could be pivotal in fostering more resilient farming communities in the region.

Hassan et al. (2008) [11] in the study "Determinants of African farmers' strategies for adapting to climate change: multinomial choice analysis," identified key factors that aid African farmers in adapting to climate change. The research highlighted that improved access to markets, extension and credit services, technology, and farm assets such as labor, land, and capital were critical determinants. The study also emphasized that government policies and investment strategies should focus on supporting education, market access, credit availability, and dissemination of information about adaptation to climate change. This includes promoting technological and institutional methods, especially for impoverished farmers in arid regions.

These insights identify the importance of a comprehensive approach that combines resource availability and supportive policies to enhance the adaptive capacity of African farmers, ensuring their resilience against the impacts of climate change.

Sarker et al. (2013) [27] conducted a study on "Assessing the determinants of rice farmers' adaptation strategies to climate change in Bangladesh," identified several key factors that influenced farmers' adaptation choices. These factors included the gender and age of household heads, their educational background, household assets, annual farm income, farm size, tenure status, farmer-to-farmer extension, and access to credit, subsidies, and electricity.

The study highlights the multifaceted nature of adaptation decisions, suggesting that a comprehensive approach that considers social, economic and infrastructural factors is essential for supporting farmers in adapting to climate change. This underscores the need for targeted policies that enhance educational opportunities, financial support, and infrastructural development to bolster the resilience of rice farmers in Bangladesh against the impacts of climate change.

Balew et al. (2014) [4] in the study "Determinants of adoption choices of climate change adaptation strategies in crop production by small-scale farmers in Central Ethiopia," examined the factors influencing small-scale when deciding on climate change adaptation strategies for crop production. Using a binary logit model, they found that several elements increased the likelihood of farmers adopting these strategies. Key factors included access to information on climate change, larger numbers of livestock, improved soil fertility, and the frequency of droughts and floods over the past decade. Farmers' confidence in government extension workers, extensive kinship networks, and membership in local farmers' groups also played significant roles.

On the other hand, certain factors were found to reduce the probability of adopting adaptation measures. These included larger landholdings, greater distances to the nearest input

and output markets, longer travel times from residences to crop fields, financial constraints, and having friends or relatives in government positions.

The study highlights the complex interplay of socio-economic and environmental factors in shaping farmers' responses to climate change. Access to resources and information, social support networks, and logistical challenges are crucial in determining the effectiveness and likelihood of adopting adaptive practices.

Uddin *et al.* (2014) [29] in their study on "Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm-level study in Bangladesh," they investigated several key determinants influencing farmers' adaptation practices in response to climate change. They found that the major factors included the age and education level of the farmers, the size of their families and farms, their household income, and their participation in cooperatives.

Additionally, the study highlights the importance of social and economic support systems in enhancing farmers' ability to implement effective adaptation strategies. This underscores the multifaceted nature of adaptation, which relies not only on individual characteristics but also on broader community and institutional support.

Lamichhane *et al.* (2016) [17] conducted a study on "Determinants of farmers' adaptation to climate change; A case from Nawalparasi district of Nepal". In the research they identified several crucial determinants, including the involvement of economically active household members, the educational attainment of the household head, farm size, annual cash earnings, access to credit and training, and the availability of extension services. These factors collectively influence farmers' decisions in adopting strategies to mitigate and adapt to climate change impacts.

Additionally, the study highlights the role of financial resources, education, and support services in enhancing farmers' resilience and adaptive capacity in agricultural practices amidst changing environmental conditions.

Loria *et al.* (2016) [18] undertook research in the "Farmers' response and adaptation strategies to climate change in Low-Hills of Himachal Pradesh in India". Employing a binary logit model, they determined that factors such as educational attainment, household and farm size, access to irrigation water and credit, and the number of employed individuals in the household significantly have influenced on the adoption of adaptation strategies.

These findings underscore the multifaceted nature of climate change adaptation in agricultural contexts, emphasizing the pivotal roles of education, resource availability, and household dynamics in shaping farmers' responses to environmental challenges. Such insights are crucial for developing targeted policies and interventions to bolster agricultural resilience in the face of climate variability.

Ndamani *et al.* (2016) [22] conducted a study on "Determinants of farmers' adaptation to climate change: A micro level analysis in Ghana" and investigated the factors influencing farmers' adaptation to climate change at the micro level in Ghana. By employing logistic regression model identified several key determinants, including education level, household size, and annual income, access to information and credit, and membership in farmer-based organizations. These factors were found to significantly

shape farmers' strategies for adapting to climate change impacts.

The study highlights the importance of education, socio-economic factors, and institutional support in enhancing farmers' resilience and adaptive capacity amidst changing environmental conditions. Such insights are crucial for designing effective policies and initiatives aimed at promoting sustainable agricultural practices in Ghana and similar regions facing climate variability.

Opiyo *et al.* (2016) [24] studied "Determinants of perceptions of climate change and adaptation among Turkana pastoralists in Northwestern Kenya" and identified key factors influencing climate change adaptation. In the research they pinpointed several critical determinants, including the gender and educational background of the household head, household size, wealth as indicated by livestock ownership, proximity to markets, and access to credit and extension services. These factors were identified as pivotal in shaping how perceive climate change and decide on appropriate adaptation strategies.

The study underscores the intricate relationship between socio-economic variables and environmental dynamics in communities, highlighting the need for tailored interventions that account for local contexts and vulnerabilities in promoting sustainable adaptation practices.

Alemayehu *et al.* (2017) [1] in a study on "Determinants of smallholder farmers' choice of coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia" explored the factors influencing farmers' decisions regarding coping and adaptation strategies in response to climate change and variability. They found that perceived soil fertility, land tenure security perceptions, access to extension services, and the age of household heads significantly influenced the adoption of adaptation strategies. For coping strategies, factors such as agroecological zone, market access, farmer-to-farmer extension networks, landholding size, climate information availability, rainfall patterns, and the educational level of household heads played crucial roles.

Notably, the study revealed that agroecological zone negatively impacted the use of livestock sales as a coping strategy, while other variables positively influenced farmers' choices in both coping and adaptation strategies. Conversely, factors like off-farm income, community participation, livestock ownership, and temperature did not show significant influence on farmers' decisions regarding coping and adaptation strategies to climate change.

These findings underscore the nuanced interplay of environmental, socio-economic, and institutional factors in shaping farmers' responses to climate challenges, emphasizing the need for context-specific policies and interventions to enhance agricultural resilience in Ethiopia's diverse agricultural landscapes.

Begum *et al.* (2017) [5] in the study titled "Adaptation to climate change and factors affecting it in Assam" utilized a Probit regression model to examine the determinants of farmers' adaptation strategies in mitigating climate change impacts. They found that household income, engagement in extension activities, and access to credit were pivotal factors influencing the selection of adaptation strategies among farmers.

These findings highlight the critical role of financial resources, knowledge dissemination through extension services, and access to credit facilities in facilitating effective adaptation to climate change in Assam. Additionally, the study underscores the importance of targeted support mechanisms and capacity-building initiatives to bolster agricultural resilience and sustainability amidst evolving environmental challenges.

Singh's (2020) [28] in the research on "Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region, India" highlighted how fluctuations in temperature and rainfall significantly harm farmers' livelihoods. Challenges such as low income levels, limited non-farm job opportunities, and insufficient irrigated land hinder effective adaptation to climate change. However, insurance coverage and access to credit emerged as critical factors encouraging farmers to modify their agricultural practices. Adoption of early maturing seeds and drought-resistant crop varieties emerged as particularly effective strategies for enhancing profitability and resilience.

Overall, the study underscores the importance of supportive policies and investments in sustainable farming practices to mitigate the adverse impacts of climate variability on agricultural communities.

Ali *et al.* (2021) [2] conducted a study on "Rural farmers' perception and coping strategies towards climate change and their determinants: Evidence from Khyber Pakhtunkhwa province, Pakistan". The primary measures adopted by smallholder farmers include irrigation, engaging in non-farm activities, and adjusting planting schedules. The study also identified several barriers to effective climate adaptation, such as financial constraints, lack of access to suitable seeds, limited market opportunities, insecure land tenure systems, and inadequate information.

The research suggests that enhancing farmers' awareness and providing timely climate information are crucial steps towards improving adaptation efforts. This underscores the importance of targeted interventions and supportive policies to bolster the resilience of agricultural communities facing climate challenges.

Ojo *et al.* (2021) [23] conducted a study on "Quantifying the determinants of climate change adaptation strategies and farmers' access to credit in South Africa" and examined the factors influencing the adoption of climate change adaptation strategies and access to credit among smallholder farmers in their research areas. In the empirical findings, analyzed through a multivariate probit model, revealed that factors such as geographical location, extension services availability, non-farm income opportunities, farming experience, agricultural productivity (both crops and livestock), susceptibility to climate impacts, agricultural training, and access to credit significantly influenced farmers' decisions to adopt adaptation strategies.

Additionally, the study's Extended Structural Equation Modeling (ESRM) highlighted that factors like location, age, marital status, and gender also played pivotal roles in shaping farmers' adaptation decisions. Moreover, variables such as location, education level, and previous drought experiences were identified as key determinants affecting smallholder farmers' access to credit.

These results emphasize the complex array of factors that shape farmers' adaptive actions and underscore the significance of customized support mechanisms and policies to bolster climate resilience within agricultural communities.

Megersa *et al.* (2022) [20] in the study on "Perceived climate change and determinants of adaptation responses by smallholder farmers in central Ethiopia", employed a multinomial logit model to explore the factors influencing farmers' responses to perceived climate changes. Farmers generally aligned their perceptions with climate trend analyses and employed various strategies such as crop diversification, adjusting planting schedules, reducing livestock numbers, seasonal migration, crop rotation, and utilizing climate information services to adapt to climate-related challenges. Their findings revealed that household head's age and education, family size, access to extension services, and both farm and nonfarm incomes significantly influenced the adoption of these adaptation practices.

The strong associations observed between demographic, socio-institutional factors, and adaptation strategies highlight the imperative of bolstering local institutions to strengthen smallholder farmers' resilience to climate change. This underscores the importance of targeted interventions and capacity-building efforts aimed at enhancing adaptive capacities within agricultural communities.

Datta *et al.* (2022) [6] in the study on "Factors influencing the feasibility, effectiveness, and sustainability of farmers' adaptation strategies to climate change in the Indian Eastern Himalayan Foothills", using multiple linear regression analysis. The findings highlighted that local farmers are highly aware of climate change impacts and have adopted various adaptation measures, ranging from agroforestry to shifting towards less water-intensive crops and improving irrigation practices. Despite these efforts, the study reveals a discrepancy between perceived effectiveness of adaptation measures and their actual adoption rates.

Key factors positively influencing farmers' adaptation efforts include perceptions of pest infestation, satisfaction with farming, soil quality, farm size, remittances, and access to credit. Conversely, factors such as resistance to changing farming practices and conflicts with wildlife, particularly elephants raiding crops, were negatively associated with adaptation indices.

In conclusion, while farmers in the region are actively responding to climate challenges, there remains a need for better alignment between perceived benefits of adaptation strategies and their implementation on a larger scale. Addressing socio-economic barriers and enhancing support for innovative farming practices could potentially enhance the overall resilience of agricultural communities in the face of climate change.

Jatav and Singh (2023) [15] conducted study on "Determinants of climate change adaptation strategies in Bundelkhand Region", employed a binary logistic regression model to investigate the factors influencing climate change adaptation strategies among farmers. They found that farmers were more likely to enhance irrigation facilities when they have access to institutional credit, weather information, and crop insurance. Additionally, farmers recognized that rising temperatures, reduced rainfall, and declining water tables were motivating factors driving them to shift from wheat to less water-intensive

crops like chickpeas, in order to adapt to climate change.

The study emphasized the urgent need for community involvement in water-body conservation, especially as declining water tables increasingly threaten agriculture and domestic water supplies even during the rainy season. The study recommends promoting drought-tolerant crop varieties that require less water and mature quickly, which can enhance farm productivity while reducing cultivation costs. Furthermore, the implementation of an advanced regional weather forecasting system capable of providing accurate and timely information is crucial. Such systems would empower farmers to make informed decisions, adjust their cropping patterns, and adopt suitable farming practices in response to changing climatic conditions.

In conclusion, proactive community engagements, promotion of resilient crop varieties, and improved access to reliable weather forecasts are essential strategies for enhancing climate resilience in agriculture. These measures not only support sustainable agricultural practices but also mitigate the adverse impacts of climate change on rural livelihoods in the Bundelkhand Region and beyond.

Kumar *et al.* (2023) [16] in a study on "Determinants of climate change adaptation strategies in South India: Empirical evidence" they utilized discriminant and multinomial logit models to investigate the factors influencing climate change adaptation strategies among farmers in South India. Their study revealed that off-farm income, farm income, and farming experience significantly influence farmers' adoption of adaptation strategies in response to climate change. Moreover, access to climate information and literacy levels emerged as critical determinants shaping various adaptation approaches, such as crop diversification, integrated farming systems, contingency planning for agricultural operations, and the adoption of soil and water conservation techniques.

The findings highlight the importance of economic factors like off-farm income and farm income, alongside farmers' experience, in influencing their decisions to adapt to climate change. Additionally, the study highlights the pivotal role of information access and literacy in enabling farmers to implement diverse and effective adaptation strategies. Enhancing access to climate information and improving literacy levels among farmers are therefore crucial steps toward fostering resilient agricultural practices in the face of changing climatic conditions.

In conclusion, integrating economic considerations with enhanced information access and literacy is essential for promoting sustainable agriculture and resilience to climate change in South India. By supporting farmers in adopting diverse adaptation strategies, policymakers and stakeholders can contribute significantly to safeguarding agricultural productivity and rural livelihoods in the region.
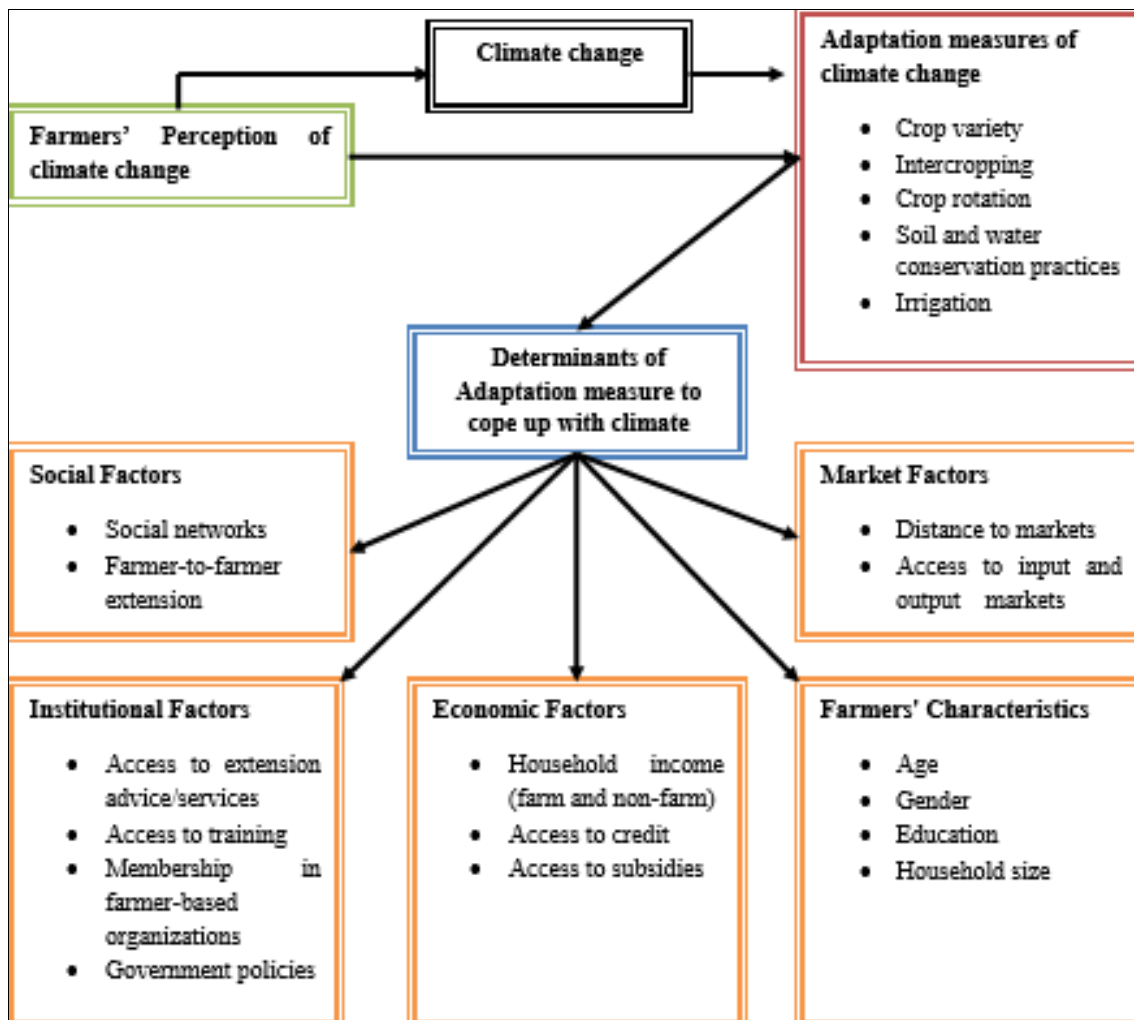

Fig 1: Determinants of Farmers' Adaptation Measures to cope up with climate change

Based on the extensive body of research reviewed here, it is evident that farmers' adaptation to climate change is influenced by a complex interplay of socio-economic, institutional, and environmental factors. Studies consistently highlighted the pivotal role of education, access to extension services, financial resources, and market infrastructure in shaping farmers' adaptive capacity. Moreover, household demographics, such as age, gender, and family size, alongside farm-specific variables like land tenure and access to credit, emerge as critical determinants.

These findings underscore the need for holistic, context-specific policies and interventions to bolster agricultural resilience. Efforts should focus on enhancing educational opportunities, improving access to climate information, promoting sustainable farming practices, and strengthening institutional support systems. Moreover, targeted investments in infrastructure and financial mechanisms are crucial to empower farmers, particularly in marginalized regions, to effectively respond to climate variability.

Moving forward, integrating local knowledge with scientific insights and fostering community participation in adaptation planning are essential. By addressing these multifaceted challenges and leveraging diverse stakeholder collaborations, policymakers can foster sustainable agricultural practices that mitigate climate risks and enhance the overall resilience of farming communities worldwide.

Conclusion
Climate change poses formidable challenges to agricultural communities across diverse regions, including India and beyond, as indicated by extensive research and findings. The impacts are projected to exacerbate, leading to significant disruptions in crop yields, livestock productivity, and overall food security. Despite the adoption of various adaptation strategies by farmers, such as crop diversification, improved irrigation practices, and adjusting planting schedules, significant gaps remain in effectively mitigating climate risks.

Key determinants influencing farmers' adaptation decisions include access to financial resources, educational attainment, access to extension services, and socio-economic factors like household income and farm size. These factors underscore the complex interplay of economic, social, and environmental dimensions in shaping adaptive capacity.

Moving forward, concerted efforts are needed to bridge knowledge gaps, enhance policy support, and strengthen institutional frameworks to bolster resilience in agriculture. This requires tailored interventions that empower farmers with timely climate information, promote sustainable farming practices, and ensure equitable access to resources and markets. Moreover, fostering collaboration between stakeholders, from local communities to international entities, is crucial for scaling up effective adaptation strategies and promoting sustainable agricultural development in the face of a changing climate. By addressing these challenges holistically, we can strive towards ensuring food security and safeguarding livelihoods amidst evolving climatic conditions.

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