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ASSESSING VULNERABILITY AND ADAPTIVE CAPACITY: CLIMATE CHANGE ADAPTATION STRATEGIES AMONG SMALLHOLDER FARMERS IN BANNU DISTRICT, PAKISTAN

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Abstract

This study explores the adaptation strategies to climate change adopted by smallholder farmers in District Bannu, Khyber Pakhtunkhwa, Pakistan. For this purpose, primary data were randomly gathered from 73 sampled smallholder farmers through a structured questionnaires and interviews schedule method. Descriptive statistics and binary logistic regression model were used to analyze the socio-economic characteristics of smallholder famers and factors effecting adaptation strategies. The findings revealed that middle aged, literate farmers with more farming experience and medium landholdings size are most probably to adopt climate adaptation strategies such as organic fertilizers, drought resilient crops, change planting periods and diversification of crop. The results further indicated that increase temperatures, Decrease/erratic rainfall, Crop diseases and Water shortage as a major climate related challenge faced to smallholder farmers. Moreover, major hurdles faces in adaptation strategies were comprises lack of funds, inadequate knowledge, and weak institutional support. The regression model analysis also indicated that the coefficient and P-value for Climate risk was (β = 0.269, P = .006), for Age was (β= .148, P = .022), for education (β = .223, P = .029), and for farming experience (β= 0.321, P = .046), while for landholding size (β= 0.481, P = .029) had significantly influenced adaptation strategies. This study emphasize the need for targeted interventions to support adaptive capability and promote sustainable agriculture among smallholder farmers. It is recommended that government and NGOs should improve farmer training programs and ensure regular, accessible extension services focused on climate resilient agricultural practices and financial institutions and agricultural support organizations should design accessible credit schemes and inputs subsidies

to facilitate widespread adoption of climate adaptation strategies.

INTRODUCTION

Background and Global Context

Climate change is a substantial environmental issue and effects all economic sectors, containing energy, health, water, biodiversity, and agriculture system of worldwide. The increasing temperatures, irregular rainfall, and increased frequency of extreme climate events have disrupted traditional agricultural methods, intimidating food security and livelihoods, specifically in developing countries. Smallholder farmers, who constitute a substantial portion of the agricultural labor force, are particularly vulnerable due to their partial resources and adaptive capacities. Studies have revealed that smallholder growers habitually depend on rain-fed agriculture, creating them susceptible to climatic variations (Nadeem et al., 2024). As a result, sustainable agricultural productivity is expected to decrease due to ecological changes, mainly affecting those reliant on food production. In developing countries, such as Pakistan, feel the majority of climate change effects due to their susceptibility and inadequate alleviation capacity. Agriculture in these areas faces severe effects from changes temperature, altered rainfall patterns, floods, droughts, and adverse effects on water and land resources (Khan et al., 2024).

In response to these challenges, several climate adaptation strategies have been employed universally. These climate adaptation strategies comprises of changing dates of planting, adopting different drought-resistant crop varieties, implementing water conservation technique, and livelihood income sources diversification. For example, in developing countries, farmers have moved to early maturing crop varieties and integrated agroforestry technique to improve resilience. Likewise, in Southeast Asia, the adoption of integrated pest management and conservation agriculture has shown auspicious results in alleviating climate risks (Ali et al., 2021).

Global Scenario of Climate Change and Adaptation Strategies

Climate change poses is a major threat to the universal agrarian systems, predominantly affecting smallholder farmers in the susceptible zones due to their dependence on rain-fed agriculture and partial adaptive capability. The increasing temperatures, erratic rainfall designs, lengthy droughts, and increased frequency of extreme climate events have interrupted farming schedules, declined crop yields, and destabilized food security in various parts of the globe. Previous studies from Africa and Asia specify a rising awareness about climate change among agrarian communities, but their ability to respond efficiently varies based on institutional and socio-economic factors. In the northern Uganda, study noted that access to agricultural extension services, education, and farmers' organization membership had considerably improved adaptive responses to climate change (Atube et al., 2021). In Ghana's savannah region, small farmers adopted diversification of crop, fluctuating dates of planting, and better seed varieties, but their

strategies were strongly affected by age, education, and access to information (Incoom et al., 2025). Likewise, in Ethiopia, smallholder farmers' opinions of climate risks shaped their decisions to adopt soil and water conservation methods, early planting, and diverse cropping as means to manage with shifting climatic patterns (Bogale, 2024).

Universally, climate change adaptation strategies among smallholder farmers reflect a combination of traditional knowledge and modern methods, though adoption rates habitually depend on institutional support, access to resources, and local ecological contexts. In Indonesia, Mujayin and Rahayu (2024) documented livestock focused adaptations containing enhanced shelter, feeding, and disease management to address climate related strain on animals. According to Ogundeji (2022) they observed that adaptation strategies not only protected smallholder farmers from climate shocks but also enhanced food security through practices like irrigation, mulching, and climate resilient cropping methods. Meanwhile, Madamombe et al. (2024) highlighted the significance of climate change awareness in promoting adaptive action in Zimbabwe's semi-arid zones, where water conservation, crop rotation, and community training programs were prevalent. Likewise study further revealed that gender, income, education level, and access to markets were critical socio-economic determinants influencing the choice of adaptation strategies among farmers in South Africa. These global case studies collectively underscore the urgent need for inclusive, location-specific, and knowledge-driven adaptation policies should help smallholder farmers to effectively adopt to the adverse effects of climate change (Dyanty et al. 2025).

National Scenario: Pakistan Agricultural Vulnerability

Climate change in Pakistan is increasingly recognized as a major risk to the farming sector, with a key influences on water availability, crop efficiency, and rural livelihoods income source. Increasing temperatures, irregular rainfall, and rising frequency of extreme weather events likes floods and droughts have interrupted outdated agricultural methods throughout the country. Growers are facing heightened uncertainty, leading farmers to make significant changes in livelihood strategies. Climate change is pushing many smallholder farmers to consider exiting farming completely, mostly in regions where adaptation resources are limited. For those who remain in farming, adaptation strategies include changing crop types, adjusting planting schedules, adopting water saving irrigation methods, and depend on more on off-farm income sources to buffer risks. The decision to adapt or exit farming typically hinges on access to capital, education, and institutional support, emphasizing the socio-economic differences in susceptibility and resilience within rural Pakistan (Ahmad et al. 2024). In Punjab, particularly in southern zones such as Dera Ghazi Khan, smallholder farmers are representing an increased awareness of climate change and are actively looking for ways to adapt, though their efforts are habitually constrained by economical, informational, and technical hurdles. In Punjab farmers identify long term climatic changes such as decline rainfall and temperature extremes their adaptation strategies are frequently reactive, often limited to adjusting irrigation

frequency or switching to short time crop varieties (Nadeem et al. 2024). In Dera Ghazi Khan, a broader range of adaptation strategies, comprising diversification of crop, rainwater harvesting, and soil management practices. However, deficiency of timely access to weather forecasts, weak services of agricultural extension, and inadequate institutional coordination hinder the efficiency of these adopting strategies. These studies communally highlight the significance of targeted policy involvements that strengthen local adaptation capacity through farmer training, financial incentives, and better access to climate information systems, which are crucial for building resilience in Pakistan's susceptible agricultural landscapes (Shah et al., 2024).

Pakistan farming sector is highly vulnerable to climate change effects. The country diverse agro ecological zones experience changing degrees of susceptibility, with arid and semi-arid zones being the most affected. Rising temperature, floods and frequent droughts, have led to substantial losses of crop and decrease agricultural productivity. The Intergovernmental Panel on Climate Change has planned that Pakistan will face increased water shortage and heightened food insecurity if adaptation procedures are not applied on timely (IPCC, 2022). In response, Pakistan the government has introduced numerous programs aimed at improving climate resilience in farming. The climate-smart agriculture initiative promotes techniques likes' conservation tillage, effective irrigation systems, and use of climate-resilient crop varieties. Likewise, the "Billion Tree Tsunami" project aims to restore degraded forests, thereby contributing to carbon sequestration and ecosystem restoration (Khan et al. 2022).

Regional Focus: Khyber Pakhtunkhwa and District Bannu

Climate change poses persistent challenges for the agricultural sector in Pakistan specifically in Khyber Pakhtunkhwa. Temperatures rising, rainfall pattern changing, and frequent droughts, have disrupted traditional farming practices. Smallholder farmers in KPK face increasing pressure as climate-related shocks occur more frequently, impacting yields, water resources, and food security. In KPK drought prone districts, small growers have adopted different adaptation methods. These methods includes shifting crop types, rescheduling planting dates, and investing in water saving techniques such as tube wells and rainwater collecting. Conversely, the efficiency of these adoptive strategies is habitually inadequate by socioeconomic challenges. These comprise low educational levels, inadequate access to climate information, and a lack of extension services (Khan et al., 2022). Bannu district is located in the southern side of Khyber Pakhtunkhwa is characterized by semi-arid conditions, making farming mostly on rain dependent. In Bannu district the smallholder farmers' faces various challenges including of water shortage, degradation of soil, and limited access to modern agricultural machineries. However, there is a lack of area specific studies concentrating on these issues and the climate adaptation strategies used by the smallholder farmers. Earlier study in Khyber Pakhtunkhwa has mainly focused on northern districts such as Swat and Chitral, overseeing the unique issues faced by the farmers in southern areas like Bannu. Understanding the localized climatic adaptation strategies in Bannu is essential for developing targeted interventions

that address the specific needs of these communities (Ali et al., 2023).

Climate change is increasingly affecting smallholder farmers across the globe, with substantial consequences for crop produces, food security, and rural livelihoods. However, various global and national level studies have explored climate adaptation in agriculture, they often present generalized findings that overlook the local context and specific susceptibilities of small scale farmers in areas like District Bannu. Previous studies in Pakistan, particularly in provinces like Sindh and Punjab, has mainly concentrated on large scale farming while partial attention has been given to the southern part of Khyber Pakhtunkhwa specially to district Bannu. In Khyber Pakhtunkhwa, studies have been focused on around districts like Mardan, Charsadda, Malakand, and Swat, leaving knowledge gaps in under researched, semi-arid zones such as district Bannu. Smallholder farmers in Bannu district face unique climate related problems such as unpredictable rainfall, soil degradation, and water shortage compounded by poor access to extension services and partial economic resources. The current study purposes to fill that gap by exploring the localized adaptation strategies practiced by the small farmers, the socio-economic factors influencing their decisions, and the hurdles they face.

Research Questions

- What specific climate change vulnerabilities are perceived and experienced by smallholder farmers in District Bannu?
- What types of climate adaptation strategies are used by a smallholder farmers to mitigate climatic risks?
- How effective are these adaptation strategies, and what limitations do farmers face in implementing them?

Objectives of the Study

- To identify the specific climate change vulnerabilities perceived and experienced by smallholder farmers in Bannu District.
- To categorize the range of adaptation strategies used by these farmers to mitigate identified climate risk.
- To evaluate the perceived effectiveness and limitations of the predominant adaptation strategies utilized within the study area

METHODOLOGY

Universe of Study

District Bannu was selected as the universe of study where is a large percentage of the population is primarily reliant on agriculture and livestock for their livelihoods. District Bannu is highly susceptible to the effects of climate change, such as irregular rainfall, rising temperatures, and water shortage, which directly affect agricultural efficiency and rural livelihoods while has also issues related to conflict, displacement, and partial access to modern agricultural techniques, making it a related area for examining climate adaptation strategies. The selection of this district allows for a deeper understanding of how smallholder farmers in a resource constrained and climate affected area cope with ecological and socio-economic pressures. The sample design for this study followed a purposive sampling technique to confirm comprehensive analysis of the study area. In the 1st stage, Bannu District was selected purposively due to its vulnerability to climate change and dependence on agriculture. In

the 2nd stage, Tehsil Bannu was chosen from the four tehsils namely Bannu, Domel, Kakki, and Bakha Khel. The 3rd stage involved the selection of one Union Council namely UC Hassani from Tehsil Bannu, representing the rural farming population. In the 4th stage, two villages namely Basya Khel and Bazida were selected from the selected Union Council based on their agricultural engagement and accessibility. Finally, in the fifth stage, a total sample size of 73 sampled households was determined using Yamane's formula, from which 46 from Basya Khel and 27 from Bazida from total of 264 sample households. The Yamane formula equation is given below;

$$n = \frac{N}{(1+Ne^2)} \quad \text{..... (1)}$$

Whereas:

"n" is selected sample size, "N" is the total number of smallholder farmers household in the study area and "e" is precision which is set at 10 percent (0.010)

Data Collection and Analytical Framework

Primary data were gathered from the sampled smallholder farmers using a structured questionnaire and face-to-face interviews. A well-structure questionnaire was designed specifically for this purpose. It contained a mix of closed-ended and open-ended questions to capture both numerical data and personal insights. To analyze the data Descriptive statistics were used to observe the socio-economic and climate change related features of the sampled smallholder farmers. However, the binary logit regression model was used to examine the climate risk, socio-economic and demographic factors influencing the adoption of climate adaptation strategies in the study area. The general equation of binary logit regression model is under:

$$Logit\ (p) = ln\ (\frac{P}{1-P}) = \beta_0 + \beta_1 X_1 + \beta_2 X_2, + \beta_3 X_3 + \beta_4 X_4 + \beta_5 D_1 \dots\dots\dots\dots\dots (2)$$

Whereas:

- Logit(P) is a Dependent variable (Climate adaptation strategies = 1= adopted, 0 = non-adopted)
- β_0 is Intercept
- $\beta_1,\beta_2,\dots,\beta_5$ is a Regression coefficients to estimate and
- X_{1i},X_{2i},X_{3i},X_4, D_1 is explanatory variables

The specified binary logit regression model for this study is:

$$CAS_i = \beta_0 + \beta_1 Age_i + \beta_2 Edu_i + \beta_3 FE_i + \beta_4 FS_i + \beta_5 CR_i \quad \text{..... (3)}$$

The following table explain the variables description which includes in the model.

Table 1: ***Description of Variables used in Logit Regression Model***

Variable	Code	Variable description	Measurement	Exp. sign
Dependent	Y	Climate adaptation strategies	1= adopted, 0 = non-adopted	~
Independent	X_1	Smallholder farmer age	Years	±
Independent	X_2	Farmer education	Years of schooling	+
Independent	X_3	Farming experience	Years	+
Independent	X_4	Farm size	Acres	+
Independent	D_1	Climate risk perception	1= serious threat, 0 = No	+

RESULTS

Descriptive Statistics

The table no. 2 presented the descriptive statistics of the explanatory variables of smallholder farmers. The table findings revealed that 67% of smallholder farmers perceive climate risk as a serious issue, while the farmers' average age is about 50 years, with minimum 25 and maximum of 75 years, with a mean experience of farming was 17 years. On average, stallholder farmers had 8 years of education and operating 6.71 acres of land, indicating moderate educational achievement and medium sized landholdings in the study area.

Table 2: ***Descriptive Statistics of Explanatory Variables***

Independent variables	N	Minimum	Maximum	Mean	Std. deviation
Climate risk perception	73	0	1	.67	.473
Smallholder famers age	73	25	75	50	11.854
Farmers education	73	0	18	8	6.407
Farming experience	73	7	35	17	5.707
Farm size	73	2	15	6.71	2.638

Own calculation

Faced Climate Related Challenges

Smallholder farmers are progressively facing an extensive range of climate change related issues that affect their agricultural efficiency and source of livelihoods. The table 3 findings revealed that most commonly reported challenge in both villages is decreased or erratic rainfall, affecting 40 percent of the total sampled smallholder farmers from which 25 percent were from Basya Khel and 15 percent from Bazida village, representing a key disruption to rain fed agriculture and water availability. Likewise, increased temperatures and water shortage were noted by 23 percent of the sampled farmers respectively. The remaining (14%) of the sampled farmers were reported challenge like crop diseases, which are usually aggravated by climate variations, reflecting a growing but still less dominant concern. This result overall, indicated that erratic rainfall and water scarcity are the most pressing climate-related challenges, significantly impacting the productivity and resilience of smallholder farmers in the region.

Table 3: ***Distribution of Smallholder Farmers' According To Faced Climate Related Challenges***

Face climate related challenges	Basya Khel	Bazida	Total
Increase temperatures	13%	10%	23%
Decrease/erratic rainfall	25%	15%	40%
Crop diseases	10%	4%	14%
Water shortage	15%	8%	23%
Total	**63%**	**37%**	**100%**

Own calculation

Farmer's Opinions by Using Different Climate Adaptation *Strategies*

Climate change postures significant challenges to agricultural sustainability, predominantly for smallholder farmers who depend on heavily on climate sensitive resources. To cope with its

adverse effects, smallholder farmers adopt numerous climate adaptation strategies. Table 4 revealed the distribution of smallholder farmers' opinions concerning the adoption of numerous climate change adaptation strategies. Among the climatic adapting strategies listed, 86 percent of the stallholder farmers was confirming used organic fertilizers, indicating a rising consciousness of sustainable soil management technique to increase resilience against climate variation. However, 84 percent of farmers using drought resistant crop varieties, reflecting their proactive response to decreasing water availability and irregular rainfall patterns. Diversifying crop or intercropping was adopted by 78 percent of the smallholder farmers, representing that various sampled farmers recognize the benefits of spreading risk and improving productivity under shifting climatic conditions. Moreover, 66 percent of sampled smallholder farmers acknowledged changing cropping patterns as a response to climate related challenges, while 64 percent stated that changing planting and harvesting dates, a flexible strategy to align crop cycles with fluctuating weather conditions. This result overall, reflect a positive opinion and relatively high adoption of climate adaptation strategies by sampled smallholder farmers in the study area.

Table 4: ***Distribution of Smallholder Farmers' By Adapting Different Climate Adaptation Strategies***

Adaptation strategies	Smallholder Farmers Opinions	
	Yes	No
Change cropping pattern	66%	34%
Drought resistant crop varieties	84%	16%
Crop diversification/intercropping	78%	22%
Changed planting/harvesting dates	64%	36%
Use organic fertilizer	86%	14%

Own calculation

Faces Challenges in Climate Adapting Strategies

Table 5 revealed the distribution of smallholder farmers' faced various challenges in assuming climate adaptation strategies. The table result indicated that majority 48 percent of sampled smallholder farmers reported that lack of fund is a major hurdle to implementing adaptation strategies, followed by 25 percent of sampled farmers reported lack of knowledge was the most substantial constraint, and 18 percent of the sampled farmers stated that insufficient support of government is a key constraint in the study area. The remaining (9%) sampled smallholder farmers reported that inputs unavailability is one of the problems that hinder farmer's adaptive capability. The overall result emphasizes that partial access to economic resources, agriculture extension services, and timely climate information usually restricts their capability to applied effective adaptation procedures. These limitations not only hamper adaptive ability but also threaten long term agricultural efficiency and food security in rural communities.

Table 5: *Smallholder Farmers' Faced Challenges on Adopting Climate Adaptation Strategies*

Faced challenges adapting strategies	Basya Khel	Bazida	Total
Lack of knowledge	17%	8%	25%
Lack of funds	30%	18%	48%
Inputs unavailability	5%	4%	9%
Lack of government support	11%	7%	18%
Total	**63%**	**37%**	**100%**

Own calculation

Factors Affecting the Adoption of Climate Adaptation Strategies

The following table 6 shows binary logit regression model relationship and effect of socio-economic and climate risk variables of smallholder farmers on adapting climate adaptation strategies odds ratios. The main and control variables in the table includes Climate risk perception, age, education, farming experience, and landholding size. The study indicated that the climate risk perception was positively correlated with climate adaptation strategies. The study revealed that coefficient value for climate risk was (β = 4.269 and P = .006), which is statistically significant at 1% level of significant, indicating that if a unit increase in perception of climate change as a serious threat, increases 7044.7 percent are more likely to adopt climate adaptation strategies of smallholder farmers as compared to non-perceived climate risk. The study revealed that the coefficient for age was (.148) and P-value was (0.022) has a positive and statistically insignificant at 5% level of significant. This means that age has a strong and statistically significant influence on the likelihood of adopting climate adaptation strategies. The odds value (1.159) indicated that, if a one year rise in age of the smallholder farmers, the odds of adopting climate adaptation strategy increases by about 15.9 percent, holding other factors constant. Older smallholder farmers may experience and possess more knowledge in adopting strategies as compared to younger farmers. However, the table result indicated that education had positive and statistically significant association with climate change adaptation. The regression co-efficient value for education is (β=.223, p=.025 and odd ratio= 1.250), it means that each additional year increase in education level, increases the odds of adopting climate adaptation strategies by 25%. Educated sampled respondents are more likely to understand climate change related information, attend training, and access climate smart resources. Education improves the capability to process information, manage risks, and adopt innovative strategies (Khan et al., 2022).

Like-wise farming experience had positively influenced the likelihood of adopting climate adaptation strategies in the study area. The regression co-efficient for farming experience is (β =.321, p = .046 and odd ratio= 1.378), its means that, each addional year increase in farming experience, increases the odds of adaptation strategies by 37.8%. Experienced smallholder farmers are more conscious of long-term climatic changes and may have already experimented with

coping mechanisms. Farming experience contributes to practical knowledge, increasing confidence in adopting relevant climate adaptation strategies. Moreover, landholding size highlighted a positive and significant effect on adaptation strategy adoption at 5% level of significant. The regression co-efficient for landholding was (β =.481 and p = .029 and odd ratio= 1.617), means that if one acre increase in landholding size increases the odds of climate adaptation by 61.7% in the study area. Smallholder farmers with more landholdings may have better financial capability, more assets to invest in climate resilient methods (e.g., drought-resistant crops, irrigation systems), and greater flexibility to experiment on part of their land. The constant term is negative and statistically significant. This indicates the log-odds of adopting climate adaptation strategies when all explanatory variables are zero (i.e. a hypothetical farmer with climate risk, age = 0, no education, no experience, and no landholding). The negative value of the constant term indicated that in the absence of any socio-economic support factors, the baseline likelihood of adopting climate adaptation strategies is very low. This is logical because a smallholder farmer without age, education, experience, or landholding would be highly unlikely to adopt any meaningful strategy. The R^2 value (0.682) indicated that model explains 68.2% variation in the adoption of climate adaptation strategies is explained by the model which indicated a good model fit. Conversely, the likelihood ratio (LR) Chi^2 test was performed to measure the statistical significance of all the independent variables. The test shows a Chi^2 value of 40.443 with a p-value of 0.000, suggested that the overall model is statistically highly significant and a good explanatory strength of the predictors.

Table 6: ***Binary Logit Model Estimates of Factors Influencing Adoption of Climate Adaptation Strategies***

Independent variables	*Co-efficient (β)*	*S. Error*	*Wald*	*Odds ratio*	*Sig.*
Climate risk perception	4.269	1.556	7.526	71.447	.006
Farmer age	.148	.046	5.260	1.159	.022
Education	.223	.102	4.782	1.250	.029
Farming experience	.321	.161	3.980	1.378	.046
Landholding size	.481	.221	4.748	1.617	.029
Constant	-15.340	5.612	7.471	.000	.006

Number of obs. = 73 R^2 = 68.2 % Chi^2 P-value = .000 LR Chi^2 value = 40.443

CONCLUSION AND RECOMMENDATIONS

This article determines that smallholder farmers in District Bannu are progressively conscious of climate change and had adopted a kind of adaptation strategies to cope with its adverse effects. The most frequently adopted practices

include use of organic fertilizers, changing planting dates, drought resilient crop varieties, and intercropping, reflecting a proactive technique to climate resistant. However, a substantial percentage of sampled farmers still lack of complete involvement in adaptation strategies, predominantly due to partial access to capitals, knowledge, and institutional support. Despite, their willingness, mostly sampled smallholder farmers faced challenges such as lack of funds, inadequate training, and weak extension services, which delay effective adoption strategies in the study area. Moreover, sampled smallholder farmers perception about climate risk and socio-economic characteristics like age, education, farming experience, and landholding size had statistically significant affect the likelihood of adopting climate adaptation strategies in the study area. The study overall concludes that, empowering smallholder farmers through education, extension services, and comprehensive policy interventions is vigorous for promoting sustainable agriculture under changing climatic conditions. Based on the study findings it is suggested that government and NGOs should improve farmer training programs and confirm regular, accessible extension services concentrated on climate resistant agricultural methods. Agricultural support organizations should design accessible credit schemes and inputs subsidies to enable extensive adoption of climate adaptation strategies. There is a pressing need for stronger government participation and institutional frameworks to support smallholder farmers through policy advocacy, infrastructure development, and emergency response mechanisms for climate related shocks.

FUTURE RESEARCH

Future study should consider a greater sample size and include longitudinal data to well capture long-term adaptation trends and causal relationships. Moreover, further studies could examine the role of institutional support, access to climate information services, and financial inclusion in strengthening farmers' adaptive capacity.

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