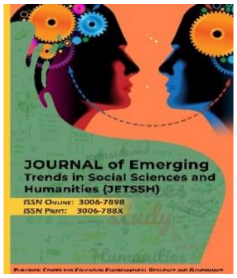

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Developing an Integrated Climate Resilience Model for Rural Households in Sindh, Pakistan: The Role of Climate-Smart Agriculture and Financial Inclusion in Poverty Reduction

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ABSTRACT

This study seeks to create and validate an integrated model of climate resilience; specifically, how climate smart agriculture (CSA) and financial inclusion are associated with poverty alleviation via climate resilience at the household level. Sequential explanatory mixed-methods design, based on a pragmatic research paradigm and an abductive approach, was used. A structured questionnaire was used to gather quantitative data from 169 farming households in the rural area and Smart PLS 4 was employed to analyze the proposed model. In order to enrich and illustrate quantitative findings, 09, semi-structured interviews were conducted with farmers, agriculture extension officers and microfinance practitioners. Qualitative data was analyzed by thematic analysis using Atlas.ti software. Overall findings integrated results will showcase that Climate Smart Agriculture and Financial inclusion have a strong impact on the climates resilience of households which in turn contributes to the reduction of poverty. The study also focuses on identifying factors in the context which affects the successful implementation of strategies for building resilience within communities in a rural setting. The proposed integrated climate resilience model has not only theoretical contribution in the climate resilience literature but it further puts forth policies for the policymakers, development bodies and financial institutions to encourage sustainable agriculture, build adaptive capacity and reduce rural poverty in climate-vulnerable areas of Pakistan.

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Introduction

Climate change has become one of the most critical issues of sustainable agricultural production, food security and rural livelihoods in the developing nations. With the rise in temperatures, fluctuations in rainfall, longer droughts, and frequent floods, agricultural production has been drastically lowered and farm households have become more vulnerable, especially in the climate-vulnerable regions like Sindh, Pakistan. Climate-induced shocks have further elevated livelihood insecurity and exacerbation of the socio-economic disparity in the rural communities which rely heavily on agriculture for their livelihoods. Building resilience among households is therefore a prime concern and key to sustainable rural development for long-term food security. Emerging evidence indicates that sustainable agriculture is a key enabler for better adaptive capacity, and the influence of environmental hazards on people's livelihoods in rural communities (Ahmed et al., 2025). Moreover, Afshar and Hussain Shah (2025) add that resilient agricultural systems play a role in food security in supporting households against climatic disruptions.

The concept of climate-smart agriculture is gaining more and more importance, as it is interpreted as a general approach that can at the same time improve agriculture productivity, build adaptive capacity and reduce climate risks. Sustainable farming methods, precision agriculture, better water usage and the cultural addition of agricultural and crop varieties resilient to climate change helps households make more effective adjustments to the uncertainties of the environment and helps to generate better long-term livelihood returns. In addition to technologic development, however, these practices will require an access to knowledge, infrastructure, institutional support, and finances. Khan et al. report that development of infrastructure and technologies for adaptation to climate change significantly increase food security and farmers' adaptive capacity. Although some challenges are in place to implement the precision agriculture and smart farming applications, a transformation in climate-resilient crop production is being realized through the use of such precision and smart farming technologies, according to Dilshad et al. (2025). Financial limitations have been mentioned as one of the main constraints for the adoption of climate-smart agriculture by the farmers in Pakistan (Aslam et al., 2023). Similarly, Timu et al. (2024) emphasize the need for innovative financial products tailored to climate change that will improve the capacity of smallholder farmers to finance adaptation strategies to climate change in their farms.

In recent months, financial inclusion has been a hot topic for discussion as one of the main triggers for rural resilience; better access to financial services, including credit, savings, and risk management such as insurance, will lead to better utilization of financial resources for households and banks undertaking adaptation investment. In addition, digital financial services have increased the opportunities of marginalized farmers, as it lowers transaction costs, enhances access to formal financial systems, and improves access and engagement with the markets. The study by Asante et al. (2025) clearly shows the strong potential for digital financial inclusion to incentivize the adoption of climate smart agricultural technologies by smallholder farmers. According to Luo and Chen (2025), digital financial inclusion is associated with a decrease in multidimensional poverty through the impact it has on boosting households' resilience to climate risks. The study by Ali et al. 2025 also established that under extreme weather conditions, financial inclusion boosts agriculture productivity and sustainability. The authors Siddiqui et al. note that inclusive financial mechanisms need to be all inclusive and take local cultural and institutional contexts into account to reap maximum benefits in terms of social and economic gains. Similarly, Narijo et al. (2024) argue that inclusive projects for community-based development improve sustainable socioeconomic outcomes by involving more institutions and empowering locals.

Although there has been a tremendous amount of research interest in these two concepts, there is very limited empirical research that relates these two mechanisms together and their role in improving household climate resilience and poverty reduction in the rural context of the province Sindh in Pakistan. Previous studies have tended to either focus on climate adaptation or agricultural productivity or on financial inclusion without sufficient attention to their combined effect on building resilience of vulnerable rural households. The continuity of structural inequalities in rural livelihoods of Sindh is demonstrated by the analysis performed by Shah et al. (2025) that has emphasized the need for project-oriented approaches to development in the region. According to Ahmed et al. (2025), climate resilience strategy is critical for sustainable agricultural development in climate sensitive areas in integrated approaches. The need for coordinated interventions incorporating financial accessibility, institutional support, and technological innovation to support effective adaptation has been emphasized by Hussain et al. (2025). In this regard, the present study conceptualizes and empirically tests an integrated climate resilience model which relies on the linkages of financial inclusion and climate smart agriculture for improving rural household climate resilience and alleviating rural poverty in the context of Sindh, Pakistan.

Research Aim

To develop and validate an integrated climate resilience model for rural households in Sindh, Pakistan by examining the role of climate-smart agriculture and financial inclusion in enhancing household climate resilience and reducing poverty through a sequential explanatory mixed-methods approach.

Research Objectives

1. To examine the effect of climate-smart agriculture on household climate resilience among rural households in Sindh, Pakistan.
2. To investigate the effect of financial inclusion on household climate resilience among rural households in Sindh, Pakistan.
3. To assess the influence of household climate resilience on poverty reduction and validate the proposed integrated climate resilience model
4. To explore rural households' and key stakeholders' perceptions regarding the barriers and enabling factors influencing the adoption of climate-smart agriculture and financial inclusion practices.
5. To develop a context-specific integrated climate resilience model for rural households in Sindh, Pakistan.

Literature Review

Climate resilience has emerged as a key and frequently used concept in the field of sustainable development, representing the ability of households and agricultural systems to anticipate, absorb, adapt and recover from climate shocks without losing their livelihood. Resilience in rural economies especially those reliant on agricultural activity is not only physical, but also socioeconomic, institutional and financial, which all play a role in long-term sustainability. Climate-smart agriculture is a promising approach to building resilience through a combination of productivity and adaptation to climate change and environmental sustainability. Households' adoption of resilient farming methods has a potential to limit production risks, enhance resource use efficiency, and increase adaptive capacities in the face of uncertain climatic change. The idea that sustainable agriculture can be the key to climate resilience by harmonizing productivity and environmental protection is advocated by Ahmed et al. (2025). Similarly, Afshar and Hussain Shah (2025) point out that resilient ag struts food security and the vulnerability of the food value chain in future climate conditions. Rana and Gill (2024) have cited climate-smart agriculture to boost agricultural resilience in Pakistan as a country priority.

Technological solutions are necessary, but they can play only a complementary role in adaptation to climate changes, where the importance of financial systems in terms of providing access for households to mobilize resources for their adaptation and to cope with environmental shocks is particularly crucial. Furthermore, digital finance has helped to revolutionize rural development by increasing financial access for marginalized farming communities and facilitating sustainable livelihood diversification. Timu et al. (2024) have pointed out that climate-smart financial solutions are essential in allowing small-holder farmers to mitigate climate risks and to maintain their agricultural investments. According to Luo and Chen (2025), digital financial inclusion's effects are strongly linked to the decrease in multidimensional poverty, as a result of the improvement in the climate-related vulnerability of the households. Furthermore, financial inclusion leads to improved ability of Kenyans to invest in renewable and climate-resistant technologies, and contributes to enhance agricultural productivity during extreme weather, said Ali et al (2025). According to Aslam et al. (2023), addressing financial challenges is indeed one of the most crucial prerequisites for the quicker uptake of climate-smart agriculture in Pakistan. Overall, evidence from the literature highlights that CAFOD could provide a holistic strategy for enhancing family resilience and decreasing rural poverty, albeit at present this evidence is not specifically available within the context of the province of Sindh, Pakistan.

Hypotheses Development

Climate-Smart Agriculture and Household Climate Resilience

Climate-smart agriculture (CSA) is recognized as a suitable approach to increase the adaptive capacity, to minimize production risks and to manage and preserve sustainable resources for rural households and communities to withstand and adapt to climate change. CSA emphasizes allowing farmers to manage their farm's production more resiliently towards climatic shocks through technologies and methods like drought-resilient crops, efficient irrigation practices, soil management, and climate-smart farmer decision making. These coping strategies not only minimize environmental risk exposure, but can also enhance households' post risk coping ability. According to Ahmed et al. (2025), the benefits of climate-resilient agriculture for sustainable livelihood outcomes is to improve adaptive agriculture systems. Hussain et al. (2025) also provide a very detailed explanation of how the adoption of CSA has been associated with an overall improvement of farmers' preparedness of farmers towards climate variability. Climate-smart interventions lead to enhanced farm income resilience and lowered vulnerability in dry areas, according to Samuel et al. (2024). Afshar and Hussain Shah (2025) also offer evidence that resilient agriculture increases food security, and makes rural livelihoods sustainable. Similarly, Khan et al (2025) highlight that overall, climate resilience technologies are essential factor in agricultural adaptation and household food security. It is proposed that the following hypothesis is based on these theoretical and empirical arguments:

H1: Climate-smart agriculture has a significant positive effect on household climate resilience.

Financial Inclusion and Household Climate Resilience

Financial inclusion includes measures to boost access to financial products and services that support investments into climate adaptation and diversification of livelihoods, helping to strengthen the adaptive capacity of rural households. Leveraging financial resources like affordable credit, climate-resilient savings tools, agricultural insurance, and digital financial tools helps farmers resiliently adopt climate-smart technologies, withstand climate-related shocks and bounce back more quickly from climate-related losses. Financial access is thus an enabling mechanism which reinforces how at ease the households are, facing climatic uncertainties. In other news, digital financial inclusion was shown to have an important effect in encouraging farmers to take up climate smart agriculture technologies, as shown by Asante et al. (2025). Timu et al. (2024) emphasize the need for innovative climate-smart financial solutions to build smallholder farmers' resilience. Luo and Chen (2025) conclude that the digital financial inclusion affects the multidimensional poverty by enhancing household’s climate risk adaptive capacity. Additionally, Ali et al. (2025) provide evidence that financial inclusion helps maintain sustainable agriculture production under extreme weather conditions. Similarly, Aslam et al. (2023) also predict that better financial access would be key for enabling Pakistan's agriculture to be climate smart. Thus the following assumption is posited:

H2: Financial inclusion has a significant positive effect on household climate resilience.

Household Climate Resilience and Poverty Reduction

Household climate-resilience is defined as households' capacities to prepare for, tolerate, adjust to, and bounce back from harsh weather conditions caused by climate change and adapt to them in a sustainable way to improve their livelihoods. Having greater resilience helps households to safeguard productive assets, alter the seasonal dynamics of farm income, improve food security and diversify livelihood opportunities, thereby lowering the risk of continued poverty. Climate resilience thus serves as a longer-term approach to foster economic stability and social well-being in vulnerable rural communities. Diwakar and Mulenga (2026) believe that building climate resilience is a key enabler for sustainable poverty alleviation. According to Ahmed et al. (2025), resilient systems in agriculture boost sustainability of agricultural livelihoods and lower socioeconomic vulnerability. The resilience-building agricultural practices can result in more stable farm incomes and higher welfare in the household, as shown by Samuel et al. (2024). Khan et al. (2025) also state that food security of farming households is greatly improved with the use of climate resilient technologies. In addition, Narijo et al. (2024) point to the importance of institutional capacity building and local involvement in resilient community development efforts as they create positive socio-economic effects. Therefore, it is hypothesized that the following will occur:

H3: Household climate resilience has a significant positive effect on poverty reduction.

Climate-Smart Agriculture and Poverty Reduction

Under changing climate, CSA serves as a driver for poverty reduction by fostering climate-resilient agricultural production, farm profitability, livestock welfare and preventing production losses. CSA fosters optimal use of resources and reduces climate-related risk, thereby generating incomes and food security and consequently enhancing the welfare of households. These benefits may come as improved ability to adapt and be resilient, more than increased productivity. According to Ahmed et al. (2025), the implementation of climate-smart agriculture directly supports sustainable rural development and a better standard of living for rural households. According to Rana and Gill (2024), CSA has been recognized as a national approach towards the improvement of farmers' incomes, as well as climate resilience in Pakistan. According to Hussain et al. (2025), the adoption of climate-smart agriculture practices contributes to agricultural adaptability and sustainability. The study by Afshar and Hussain Shah (2025) proves that resilient agriculture contributes to better levels of food security and economic stability for farming communities. Additionally, Samuel et al. (2024) concludes that CSA interventions prove to be highly impactful on resilience of household incomes in areas exposed to vulnerable conditions. For this reason, the following hypothesis is suggested:

H4: Climate-smart agriculture has a significant positive effect on poverty reduction.

Financial Inclusion and Poverty Reduction

Poverty reduction is recognized as being facilitated by financial inclusion, which is expected to increase financial risk management and diversification opportunities of the households, as well as their ability to invest in productive assets. Greater access to credit, savings, insurance and digital financial services helps emerging rural households to remove liquidity constraints, better access to new agricultural technologies, and better cope with economic and climatic shocks. In turn, inclusive financial systems help to directly drive towards improvement in sustainable livelihoods and long-term poverty alleviation. Luo and Chen (2025) show that digital financial inclusion has a strong negative effect on multidimensional poverty of rural households. According to Ali et al (2025), adverse climatic conditions favorable agriculture productivity when inclusive financial systems in place. Asante et al. (2025) then demonstrate that better financial inclusion leads towards the uptake of more climate friendly agricultural innovations that boost household welfare. Given the potential for sizeable development impacts, Siddiqui et al. (2025) argue that financial inclusion programs must take into account local institutional and cultural factors to achieve optimal results. The authors of the study by Timu et al. (2024) drip down a strong argument that climate-smart finance services are critical to enhance the resilience and lower rural poverty. As a result, the following hypothesis is proposed: As such, the following hypothesis is made:

H5: Financial inclusion has a significant positive effect on poverty reduction.

Research Methodology

This study adopted a pragmatic research philosophy and an abductive research approach using a sequential explanatory mixed-methods design, which is appropriate for integrating quantitative and qualitative evidence to address complex research problems (Creswell & Creswell, 2023). The pragmatic paradigm facilitates the use of multiple methods to generate practical and context-specific knowledge, while the abductive approach enables the refinement of existing theories through empirical investigation (Saunders et al., 2023). The quantitative phase employed a cross-sectional survey of 169 rural farming households, selected through a multistage sampling technique from climate-vulnerable districts of Sindh, Pakistan. The survey data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4 to evaluate the measurement model and test the proposed structural relationships. Following the quantitative phase, the qualitative component comprised 09 semi-structured interviews with purposively selected farmers, agricultural extension officers, and microfinance practitioners to provide deeper insights into the quantitative findings. In this research, interview data was subjected to thematic analysis, following the principle of theme-based qualitative research that is interpreted based on the experience of the instrument. In qualitative research, the principle under which the theme interpretation of the data analysis technique is prepared by the researcher according to the understandings in the form of experiences of the instruments in this research is the thematic analysis technique, served by the software program Atlas.ti. Finally, both phases findings were triangulated to improve the suggested integrated climate resilience model and produce context-specific recommendations on how to enhance rural climate resilience and poverty alleviation.

Data measurement: The measurement instrument used was multi-items measurement of the scales based on previous validation (from the literature) which was used by many researchers in social scientific research in instrument development and measurement of constructs (S. Saunders, 2023). A qualitative five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree was used to measure all of the items which is suggested to be used for quantitative survey research (Creswell & Creswell, 2023). The indicators selected to measure Climate-smart agriculture were from sustainable farming practices, climate adaptation technologies, and agricultural techniques which required the use of fewer resources taken from Ahmed et al. (2025), Hussain et al. (2025), and Rana and Gill (2024). The measures of financial inclusion were derived from Asante et al. (2025), Luo and Chen (2025) and Timu et al. (2024), respectively, on the access of the bank, the access to savings, the access to insurance and the access to digital financial services. Household climate resilience was captured by a set of indicators for climate sector adaptive capacity, preparedness and recovery capability, livelihood resilience and livelihood sector adapted from Diwakar and Mulenga (2026) and Samuel et al. (2024), respectively, and poverty reduction was captured by indicators for household income, household food security, livelihood diversification, overall economic well-being, respectively, adapted from Diwakar and Mulenga (2026) and Samuel et al. (2024).

Respondents' Demographic Profile

The respondents' demographic characteristics were analyzed to get an overview of the sample and whether it was suitable for meeting the aims of this particular study. Descriptive statistics were used to analyze the variables shown by the respondents' gender, age, education, background as farmers and annual household income. These answers are included in Table 1.

Table 1: *Demographic Profile of Respondents*

Demographic Variable	Category	Frequency	Percentage (%)
Gender	Male	121	71.6
	Female	48	28.4
Age (Years)	18–30	29	17.2
	31–40	47	27.8
	41–50	52	30.8
	Above 50	41	24.2
Educational Level	No Formal Education	36	21.3
	Primary	42	24.9
	Secondary	53	31.4
	Higher Secondary & Above	38	22.4
Farming Experience	Less than 10 Years	34	20.1
	10–20 Years	57	33.7
	21–30 Years	46	27.2
	Above 30 Years	32	18.9
Annual Household Income (PKR)	Below 300,000	44	26.0
	300,001–600,000	62	36.7
	600,001–900,000	39	23.1
	Above 900,000	24	14.2

The results shown in Table 1 indicate that most of the respondents was male farmers (71.6%) which is an indication that males dominate the decision making process in rural areas of Sindh, particularly in the agriculture background. According to the results, the majority of the respondents were aged between 41 to 50 years old (30.8%) which indicated that middle-aged farmers were the greatest proportion in the study population, and very experience in farming. Education is quite an achievement as a significant proportion of respondents have finished Secondary education (31.4%), and around 20% of them deprived of any form of education training. They also possessed tremendous experience in agricultural field, with majority representing 10-20 years farming background (33.7%) which represents good practical knowledge of agricultural practices and concerns associated with climate change.

As far as its economics parameters is concerned, over a third of respondents (36.7%) indicated their annual income was between PKR 300,001 and PKR 600,000 while only 14.2% reported an annual income of more than PKR 900,000. The results indicated that the sampled households are mostly the farmers' and cultivators' households which is the most vulnerable among the households whose activities taken place in rural areas and belongs to the poorer and middle class.

Outer Loadings

Outside loadings of the measurement items for each latent dimensions were used for indicator reliability. Based on the above, the outer loading values must be greater than 0.708 which means that at least 50% of the variance of the indicator accounts for its corresponding construct (Hair et al., 2024). Indicators that load between 0.6 and 0.7 need to be retained for good composite reliability and convergent validity of the construct. The indicator reliability assessment follows up results are presented in Table 2.

Table 2: *Outer Loadings of Measurement Items*

Item	Climate-Smart Agriculture	Financial Inclusion	Household Climate Resilience	Poverty Reduction
CSA1	0.842			
CSA2	0.871			
CSA3	0.815			
CSA4	0.853			
CSA5	0.829			
FI1		0.806		
FI2		0.834		
FI3		0.879		
FI4		0.821		
FI5		0.847		
HCR1			0.861	
HCR2			0.884	
HCR3			0.832	
HCR4			0.845	
HCR5			0.816	
PR1				0.824
PR2				0.867
PR3				0.841
PR4				0.813
PR5				0.856

The values in Table 2. show that all measurement items have outer loading scores with a value of more than the suggested score of 0.708 (Hair et al., 2024) ranging from 0.806 to 0.884. The indicator loadings for Climate-Smart Agriculture were between 0.815 and 0.871, for Financial Inclusion were between 0.806 and 0.879, for Household Climate Resilience were between 0.816 and 0.884, and for Poverty Reduction the indicator loadings were between 0.813 and 0.867. The results suggest that every indicator accounts for a relatively large percentage of the variance of the desired latent construct, lending a solid understanding of indicator reliability.

Internal Consistency Reliability and Convergent Validity

A measurement model was evaluated after reliability of indicators was assessed, for Internal consistency reliability and convergent validity. Internal consistency reliability compares how the items are related to each other for the latent constructs they measure, and convergent validity measures if the items of a construct converge enough to represent the same underlying construct (Hair et al., 2024). The internal consistency of the instrument was evaluated using Cronbach's Alpha (α), rho_A, and Composite Reliability (CR) to determine the convergent validity of the instrument was measured using Average Variance Extracted (AVE). Their results suggest that Cronbach's Alpha is > 0.70, rho_A is > 0.70, and AVE is > 0.50. Table 3 presents the results

Table 3: *Internal Consistency Reliability and Convergent Validity*

Construct	Cronbach's Alpha (α)	rho_A	Composite Reliability (CR)	(AVE)
Climate-Smart Agriculture	0.904	0.907	0.928	0.720
Financial Inclusion	0.891	0.894	0.920	0.697
Household Climate Resilience	0.909	0.912	0.932	0.732
Poverty Reduction	0.896	0.899	0.923	0.706

The results of table 3. suggest high levels of internal consistency (higher than 0.7) reliability and convergent validity for all constructs. The Cronbach's Alpha for all indicators ranged from 0.891 to 0.909, which are higher than the recommended value of 0.70, thus ensuring that all indicators measure the same latent constructs. Similarly, we observed rho_A ranging from 0.894 to 0.912, thus reflecting construct reliability. Additionally, the CR indices for each construct ranged from 0.920 to 0.932, showing high internal consistency of the items of the measurement tools for each construct. In terms of convergent validity, the Average Variance Extracted (AVE) scores ranged from 0.697 to 0.732, which was higher than the 0.50 recommended by CFA. The results show that the percentage of variance explained in each construct is over 50% which indicates good convergent validity.

Discriminant Validity

Following the assessment of internal consistency reliability and convergent validity, discriminant validity was evaluated to determine whether each latent construct was empirically distinct from the others. In accordance with the recommendations of Hair et al. (2024), discriminant validity was assessed using both the Fornell–Larcker Criterion and the Heterotrait–Monotrait Ratio (HTMT). The square root of the Average Variance Extracted (AVE) for each construct should exceed its correlations with other constructs, while HTMT values should remain below the recommended threshold of 0.90. The combined results of both assessments are presented in Table 4.

Table 4: *Discriminant Validity (Fornell–Larcker Criterion and HTMT Ratio)*

Construct	CSA	FI	HCR	PR
Climate-Smart Agriculture (CSA)	0.849	0.564	0.621	0.487
Financial Inclusion (FI)	0.518	0.835	0.596	0.553
Household Climate Resilience (HCR)	0.602	0.571	0.856	0.644
Poverty Reduction (PR)	0.468	0.534	0.617	0.840

Note: Diagonal (Bold): Square Root of AVE (Fornell–Larcker Criterion)
Upper Triangle (Bold): HTMT Ratios
Lower Triangle: Latent Variable Correlations

The results presented in Table 4. provide strong evidence of discriminant validity for all constructs included in the proposed model. The diagonal elements representing the square roots of the Average Variance Extracted (√AVE) are greater than the corresponding inter-construct correlations in each row and column, thereby satisfying the Fornell–Larcker criterion. Specifically, the √AVE values ranged from 0.835 to 0.856, indicating that each construct shares more variance with its own indicators than with any other construct in the model. These findings confirm that Climate-Smart Agriculture, Financial Inclusion, Household Climate Resilience, and Poverty Reduction are empirically distinct constructs.

Similarly, the HTMT ratios presented in the upper triangle ranged from 0.487 to 0.644, all of which were well below the recommended threshold of 0.90 (Hair et al., 2024). These relatively low HTMT values indicate the absence of discriminant validity concerns and further confirm that the latent constructs measure conceptually different phenomena.

Path Coefficient Analysis (Hypotheses Testing)

Following the establishment of the measurement model's reliability and validity, the structural model was evaluated by examining the path coefficients to test the proposed hypotheses. The significance of the structural relationships was assessed using the bootstrapping procedure with 5,000 resamples, as recommended by Hair et al. (2024). The decision to accept or reject each hypothesis was based on the standardized path coefficient (β), t-statistic, p-value, and confidence interval. A relationship was considered statistically significant when the t-value exceeded 1.96 and the p-value was less than 0.05 at the 95% confidence level. The results of the hypothesis testing are presented in Table 5.

Table 5: *Path Coefficient Analysis*

Hypothesis	Structural Relationship	B	Standard Error	t-value	p-value
H1	Climate-Smart Agriculture → Household Climate Resilience	0.412	0.072	5.722	<0.001
H2	Financial Inclusion → Household Climate Resilience	0.356	0.069	5.159	<0.001
H3	Household Climate Resilience → Poverty Reduction	0.487	0.064	7.609	<0.001
H4	Climate-Smart Agriculture → Poverty Reduction	0.214	0.079	2.709	0.007
H5	Financial Inclusion → Poverty Reduction	0.268	0.074	3.622	<0.001

The findings presented in Table 5. reveal that all proposed structural relationships are statistically significant and positive, thereby providing empirical support for the hypothesized model. Climate-Smart Agriculture demonstrated a significant positive influence on Household Climate Resilience (β = 0.412, t = 5.722, p < 0.001), supporting H1 and indicating that greater adoption of climate-smart agricultural practices enhances the adaptive capacity of rural households. Likewise, Financial Inclusion exhibited a significant positive effect on Household Climate Resilience (β = 0.356, t = 5.159, p < 0.001), confirming H2 and suggesting that improved access to financial services strengthens households' ability to cope with climate-related risks. Furthermore, Household Climate Resilience exerted the strongest positive influence on Poverty Reduction (β = 0.487, t = 7.609, p < 0.001), providing strong support for H3 and emphasizing the critical role of resilience in improving household economic well-being.

The direct effects of Climate-Smart Agriculture and Financial Inclusion on Poverty Reduction were also found to be statistically significant. Specifically, Climate-Smart Agriculture positively influenced Poverty Reduction (β = 0.214, t = 2.709, p = 0.007), thereby supporting H4, while Financial Inclusion demonstrated a positive and significant effect on Poverty Reduction (β = 0.268, t = 3.622, p < 0.001), supporting H5. Although these direct effects were smaller than the effect of Household Climate Resilience, they indicate that both climate-smart agricultural practices and financial accessibility contribute independently to improving rural livelihoods. Overall, the results provide robust empirical evidence in support of the proposed integrated climate resilience model, suggesting that strengthening climate-smart agriculture and financial inclusion can significantly enhance household resilience and reduce poverty among rural households in Sindh, Pakistan.

Coefficient of Determination (R^2) and Effect Size (f^2)

Following the assessment of the structural relationships, the explanatory power of the proposed model was evaluated using the Coefficient of Determination (R^2), while the contribution of each exogenous construct was examined through Effect Size (f^2). The R^2 value indicates the proportion of variance in an endogenous construct explained by its predictor variables, whereas the f^2 statistic measures the individual contribution of each predictor to the explained variance (Hair et al., 2024). According to Hair et al. (2024), R^2 values of 0.25, 0.50, and 0.75 may be interpreted as weak, moderate, and substantial, respectively, whereas f^2 values of 0.02, 0.15, and 0.35 represent small, medium, and large effect sizes. The results are presented in Table 6.

Table 6: *Coefficient of Determination (R^2) and Effect Size (f^2)*

Endogenous Construct	Predictor Construct	R^2	f^2	Effect Size
Household Climate Resilience	Climate-Smart Agriculture	**0.568**	0.263	Medium
	Financial Inclusion		0.197	Medium
Poverty Reduction	Household Climate Resilience	**0.641**	0.372	Large
	Climate-Smart Agriculture		0.086	Small
	Financial Inclusion		0.124	Small

The findings presented in Table 6. indicate that the proposed structural model possesses satisfactory explanatory power. The predictor variables, namely Climate-Smart Agriculture and Financial Inclusion, jointly explained 56.8% of the variance in Household Climate Resilience ($R^2 = 0.568$), indicating a moderate to substantial level of explanatory power. Likewise, Household Climate Resilience, Climate-Smart Agriculture, and Financial Inclusion collectively explained 64.1% of the variance in Poverty Reduction ($R^2 = 0.641$), suggesting that the model has strong predictive capability in explaining improvements in the economic well-being of rural households. These findings demonstrate that the proposed integrated climate resilience model effectively captures a substantial proportion of the variance in the endogenous constructs.

The effect size analysis further revealed that Climate-Smart Agriculture ($f^2 = 0.263$) and Financial Inclusion ($f^2 = 0.197$) exerted medium effects on Household Climate Resilience, indicating that both constructs make meaningful contributions to enhancing adaptive capacity among rural households. Household Climate Resilience exhibited a large effect on Poverty Reduction ($f^2 = 0.372$), highlighting its central role within the proposed model. In contrast, the direct effects of Climate-Smart Agriculture ($f^2 = 0.086$) and Financial Inclusion ($f^2 = 0.124$) on Poverty Reduction were classified as small, suggesting that a considerable portion of their influence is transmitted through Household Climate Resilience. Overall, the R^2 and f^2 results confirm that the structural model demonstrates satisfactory explanatory power and that Household Climate Resilience serves as a key mechanism linking climate-smart agriculture and financial inclusion with poverty reduction.

Qualitative Analysis

Transcription of Interviews

Following the completion of the quantitative phase, the qualitative phase was conducted to provide a deeper understanding of the statistical findings and to refine the proposed integrated climate resilience model. A total of nine semi-structured interviews were conducted with purposively selected participants, including rural farmers, agricultural extension officers, and representatives of microfinance institutions. All interviews were conducted with participants' informed consent and were audio-recorded to ensure the accuracy and completeness of the collected information. The recordings were subsequently transcribed verbatim, preserving participants' original expressions, meanings, and contextual explanations. Verbatim transcription is considered a fundamental step in qualitative research because it facilitates rigorous analysis and minimizes the loss of meaningful information during data interpretation (Maxwell, 2021).

After transcription, each transcript was carefully reviewed alongside the corresponding audio recording to verify its accuracy and ensure that no responses were omitted or misinterpreted. Personal identifiers were removed from the transcripts to maintain participant confidentiality, and each respondent was assigned a unique identification code (e.g., P1–P9) for subsequent analysis and reporting. The finalized transcripts were then imported into Atlas.ti 25, where they served as the primary data source for coding and thematic analysis. This systematic transcription process established a reliable qualitative database and ensured the credibility and dependability of the subsequent analytical procedures (Creswell & Creswell, 2023; Maxwell, 2021).

Open Coding

Following the transcription and familiarization of the interview data, open coding was conducted in Atlas.ti to identify meaningful statements related to climate-smart agriculture, financial inclusion, household climate resilience, and poverty reduction. During this stage, each transcript was examined line by line, and significant words, phrases, and sentences were assigned descriptive codes representing participants' perceptions and experiences. Similar expressions across interviews were coded consistently to maintain analytical rigor and ensure comparability among participants. This inductive coding process resulted in a comprehensive list of initial codes that formed the foundation for subsequent category and theme development (Maxwell, 2021).

Table 7: *Illustrative Open Coding*

Participant Statement	Initial Code
"Using drought-resistant seeds has reduced crop losses."	Drought-resistant crops
"Modern irrigation saves water during dry periods."	Water-efficient irrigation
"Bank loans helped me purchase better farming equipment."	Access to agricultural credit
"Mobile banking has made financial transactions easier."	Digital financial services
"Training from agricultural officers improved my farming practices."	Agricultural extension support
"Floods still destroy crops despite preventive measures."	Climate vulnerability
"We have diversified our income through livestock."	Livelihood diversification
"Savings help us recover after disasters."	Household financial security
"Government support is limited in remote villages."	Institutional support gap
"Lack of awareness prevents many farmers from adopting new technologies."	Knowledge deficiency

The open coding process generated a diverse set of initial codes reflecting respondents' experiences with climate adaptation, financial accessibility, livelihood strategies, institutional support, and environmental challenges. These initial codes served as the basis for grouping conceptually similar ideas during the axial coding stage.

Axial Coding

After completing the open coding process, the identified codes were systematically examined to establish relationships among them and to group conceptually similar codes into broader analytical categories. This stage enabled the reduction of numerous initial codes into meaningful categories representing common patterns observed across the interviews. The categories developed during axial coding reflected the principal dimensions influencing climate resilience and poverty reduction among rural households in Sindh.

Table 8: *Axial Coding*

Initial Codes	Category
Drought-resistant crops, Water-efficient irrigation, Crop diversification	Climate-Smart Agricultural Practices
Access to agricultural credit, Digital financial services, Savings	Financial Inclusion
Agricultural extension support, Farmer training, Technology awareness	Capacity Building
Household financial security, Livelihood diversification, Disaster preparedness	Household Adaptive Capacity
Climate vulnerability, Institutional support gap, Limited infrastructure	Climate and Institutional Challenges

The axial coding process reduced the large number of initial codes into broader conceptual categories that explained how rural households adapt to climate-related challenges. These categories demonstrated that agricultural innovation, financial accessibility, institutional support, and adaptive livelihood strategies collectively influence household resilience and poverty reduction.

Selective Coding

Selective coding was a final step in the process of qualitative analysis whereby categories emerged during the axial coding were linked to the key themes that answered the research problems and clarified the quantitative results. These themes capture the main dimensions of the proposed integrated climate resilience model and its pathways clearly outlining the mechanisms by which climate-smart agriculture and financial inclusion can support household resilience and drive poverty reduction.

Table 9: *Selective Coding and Theme Development*

Category	Final Theme
Climate-Smart Agricultural Practices	Theme 1: Adoption of Climate-Smart Agriculture Strengthens Household Climate Resilience
Financial Inclusion	Theme 2: Financial Inclusion Enables Climate Adaptation and Livelihood Stability
Household Adaptive Capacity	Theme 3: Household Climate Resilience Facilitates Sustainable Poverty Reduction
Climate and Institutional Challenges	Theme 4: Structural Barriers Constrain Climate Resilience and Financial Accessibility
Capacity Building	Theme 5: Knowledge, Training, and Institutional Support Enhance Climate Resilience

The qualitative results were synthesized through selective coding to five major themes which together account for the climate resilience process of rural households in Sindh. Results indicate that good financial inclusion and climate-smart agricultural practices strengthened adaptive capacity of households and helped them cope with climate change effects and boost their socioeconomic situation. Indeed, the respondents consistently emphasized the lack of institutional support, access to finance, awareness and weak infrastructure, among other hindrances, to the effective implementation of climate adaptation measures. The themes support, enrich and build on the quantitative results by providing context to the statistical relationships found and by enhancing the integrated climate resilience model proposed.

Thematic Analysis

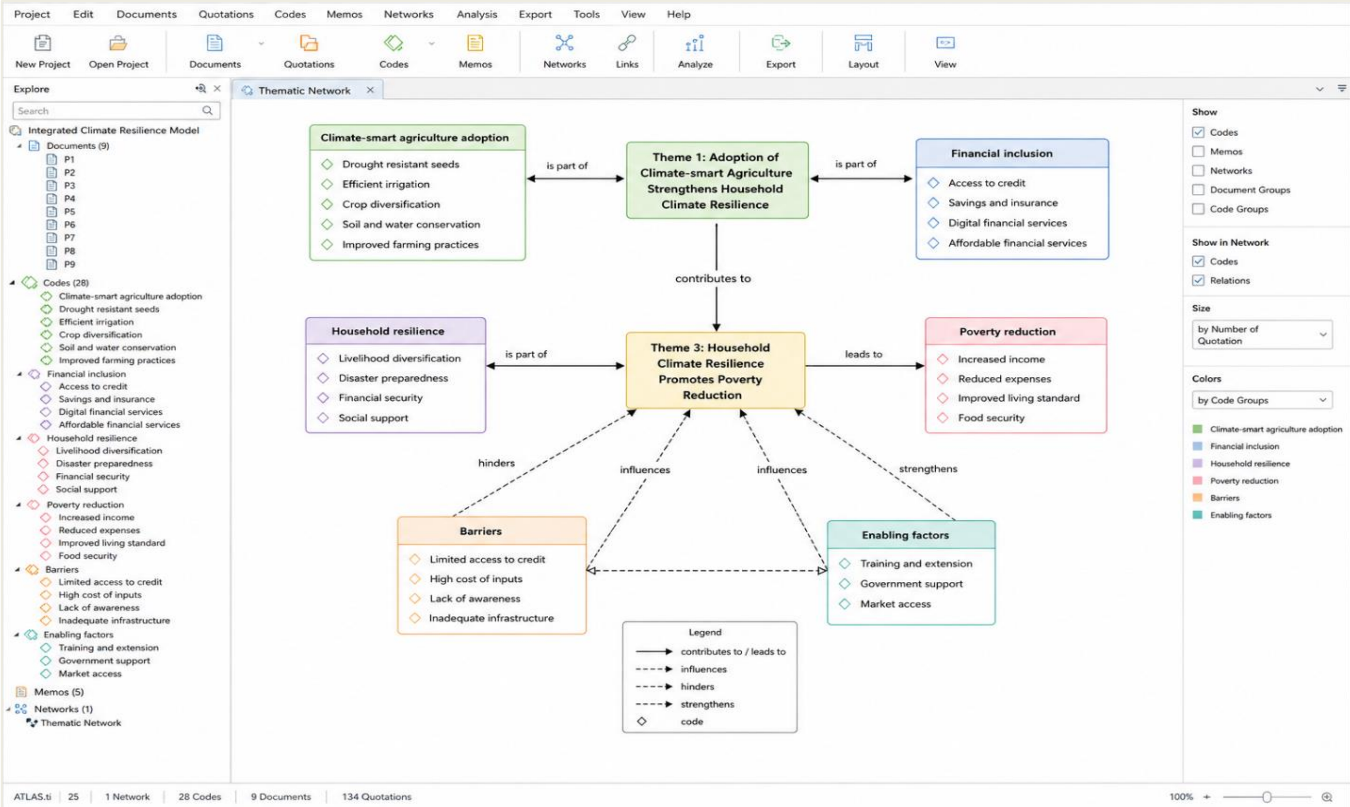
After the completion of coding process, thematic analysis was conducted to extract higher order themes to explain the role of CAS and financial inclusion in the context of household climate resilience and poverty reduction in the rural households of Sindh, Pakistan. Themes were developed by synthesizing codes and categories found in the open and axial coding as well as selective coding processes. The analysis was directed towards discovering patterns, shared experiences and context-based explanations that supplemented the quantitative analysis. To ensure a rigorous comparison of the participants' perspectives and to allow the themes to present a clear picture that is representative of the interview material, the coded segments were organized and retrieved using Atlas.ti (Maxwell, 2021).

Table 10: *Themes, Interpretation, and Representative Quotations*

Theme	Interpretation	Representative Quotation
Theme 1: Adoption of Climate-Smart Agriculture Strengthens Household Climate Resilience	Participants consistently reported that adopting drought-resistant seeds, efficient irrigation systems, crop diversification, and improved farming techniques enabled them to cope more effectively with climate variability and reduce agricultural losses.	**P3:** *"Since we started using drought-resistant seed varieties and drip irrigation, our crop losses have reduced even during periods of low rainfall."*
Theme 2: Financial Inclusion Enables Climate Adaptation and Livelihood Stability	Access to agricultural credit, savings, insurance, and digital financial services enabled farmers to invest in climate-smart technologies and recover more quickly from climate-related shocks.	**P6:** *"Without access to bank loans and mobile banking, it would have been impossible for us to invest in improved farming practices after the floods."*
Theme 3: Household Climate Resilience Promotes Poverty Reduction	Respondents perceived resilience as the ability to maintain stable income, diversify livelihoods, protect productive assets, and recover from environmental disasters, thereby improving household well-being.	**P1:** *"We now have livestock and vegetable farming together, so even if one source of income is affected, the family can still manage our expenses."*
Theme 4: Institutional and Financial Barriers Limit Climate Adaptation	Participants highlighted inadequate extension services, limited financial accessibility, weak infrastructure, and insufficient governmental support as major obstacles to climate resilience.	**P8:** *"Many farmers want to adopt new technologies, but there is little training and very limited financial support available in our village."*
Theme 5: Knowledge and Capacity Building Enhance Sustainable Adaptation	Respondents emphasized that continuous training, awareness campaigns, and technical guidance from agricultural institutions significantly improved their ability to adopt climate-smart practices.	**P5:** *"The training provided by agricultural officers helped us understand which farming methods are suitable under changing weather conditions."*

Thematic analysis shows that the linkage between climate-smart agriculture and financial inclusion is a self-reinforcing mechanism in order to enhance household resilience to climate change and boost rural livelihoods. The conversion of using adaptive agricultural technologies was consistently attributed as an increase in their adaptive capacity towards climatic shocks and sustainability of income sources in addition to the increase in financial accessibility. Respondents also recognized that resiliency matters more than technology alone, it also has to be supported by institutions, lifelong learning, and financial services. This qualitative evidence, in the form of findings, helps demonstrate the numerical findings and contextualize the results in the light of the significant relationships between the variables of the study.

Figure 1: *Atlas.TI Thematic Network*



Trustworthiness of Qualitative Findings

To ensure the rigor and quality of the qualitative findings, the study adopted the trustworthiness criteria proposed by Maxwell (2021), including credibility, dependability, confirmability, and transferability. These criteria enhanced the authenticity and consistency of the qualitative analysis while ensuring that the findings accurately represented participants' experiences and perspectives.

Table 11: *Trustworthiness of the Qualitative Findings*

Criterion	Strategy Employed	Outcome
Credibility	Verbatim transcription, prolonged engagement with the data, repeated transcript review, and participant quotations.	Enhanced confidence that the findings accurately represent participants' experiences.
Dependability	A systematic interview protocol, consistent coding procedures, and an audit trail documenting all analytical decisions.	Ensured consistency and replicability of the analytical process.
Confirmability	Coding and theme development were grounded in participants' statements, with interpretations supported by representative quotations and documented analytical procedures.	Reduced researcher bias and strengthened objectivity.
Transferability	Rich descriptions of the research context, participant characteristics, and analytical procedures were provided to enable readers to judge the applicability of the findings to similar settings.	Increased the potential applicability of the findings to comparable rural and climate-vulnerable contexts.

The evaluation of trustworthiness shows that proper methodology process has been conducted both during the qualitative aspect to improve the credibility and rigor of the results. The interpretations were highly attuned to the experiences of the participants, given by verbatim transcription, representative quotations and systematic coding as well as transparent documentation of the analytical decisions. Additionally, comprehensive descriptions of the context and participants that constitute the research contribute to the transferability of the findings to other rural communities with similar climate-related challenges.

Overall, the qualitative results provide support to the quantitative ones and offer some explanations to how the socio-economic benefits of CA and financial inclusion for enhancing household climate resilience and contributing to poverty alleviation can be understood. Incorporating both streams of evidence is likely to afford a detailed description of the proposed integrated climate resilience model and will likely benefit the overall validity of conclusions derived from the study.

Triangulation of Quantitative and Qualitative Findings

Methodological triangulation between the quantitative and qualitative results was performed during the last stage of the study. The aim of triangulation was to concurrently compare, validate, and add participants' lived experiences to the findings from the statistics, thus, helping to provide a comprehensive understanding of the relationships between components of CLUSA, financial inclusion, household climate resilience and poverty reduction (Creswell & Creswell, 2023). The quantitative results showed the statistically significant relationship between the variables of the study by using the PLS-SEM, and the qualitative results gave a glimpse of deeper explanation of the contextual mechanisms through which there were statistically significant relationships between variables of study in the scenario of rural households of Sindh. Incorporating evidence from both strands contributed to the strength of the evidence and to the development and refinement of the model for an integrated approach to climate resilience (Maxwell, 2021).

Table 12: *Triangulation of Quantitative and Qualitative Findings*

Quantitative Findings (PLS-SEM)	Qualitative Findings (Atlas.ti)	Integrated Interpretation
Climate-Smart Agriculture → Household Climate Resilience (Supported)	Participants consistently reported that drought-resistant crops, efficient irrigation, crop diversification, and improved farming practices enhanced their ability to cope with climate-related shocks.	The qualitative findings confirm that climate-smart agricultural practices strengthen household adaptive capacity, supporting the significant positive relationship identified in the quantitative analysis.
Financial Inclusion → Household Climate Resilience (Supported)	Respondents emphasized that access to agricultural credit, savings, insurance, and digital financial services enabled investment in climate adaptation and accelerated post-disaster recovery.	Qualitative evidence explains that financial inclusion improves resilience by reducing financial constraints and facilitating investment in adaptive farming technologies.
Household Climate Resilience → Poverty Reduction (Supported)	Interview participants indicated that resilient households diversified income sources, protected productive assets, and recovered more quickly from climatic disasters, thereby improving household welfare.	Both datasets demonstrate that stronger household resilience directly contributes to reducing rural poverty through sustainable livelihood improvement.

Climate-Smart Agriculture → Poverty Reduction (Supported)	Participants reported increased agricultural productivity, lower production losses, and greater income stability after adopting climate-smart agricultural practices.	The qualitative evidence explains that climate-smart agriculture contributes to poverty reduction through improved productivity and enhanced resilience.
Financial Inclusion → Poverty Reduction (Supported)	Respondents stated that financial services enabled investment in farming, education, and alternative livelihood activities, improving long-term household economic conditions.	The integrated findings indicate that financial inclusion directly enhances household welfare while simultaneously strengthening resilience against climate-related risks.
Emerging Qualitative Themes	Institutional support, farmer training, technology awareness, market accessibility, and government assistance emerged as additional enabling factors, while limited infrastructure, inadequate financial accessibility, and insufficient awareness were identified as major barriers.	These contextual factors extend the quantitative model by identifying practical conditions that facilitate or constrain the effectiveness of climate-smart agriculture and financial inclusion.

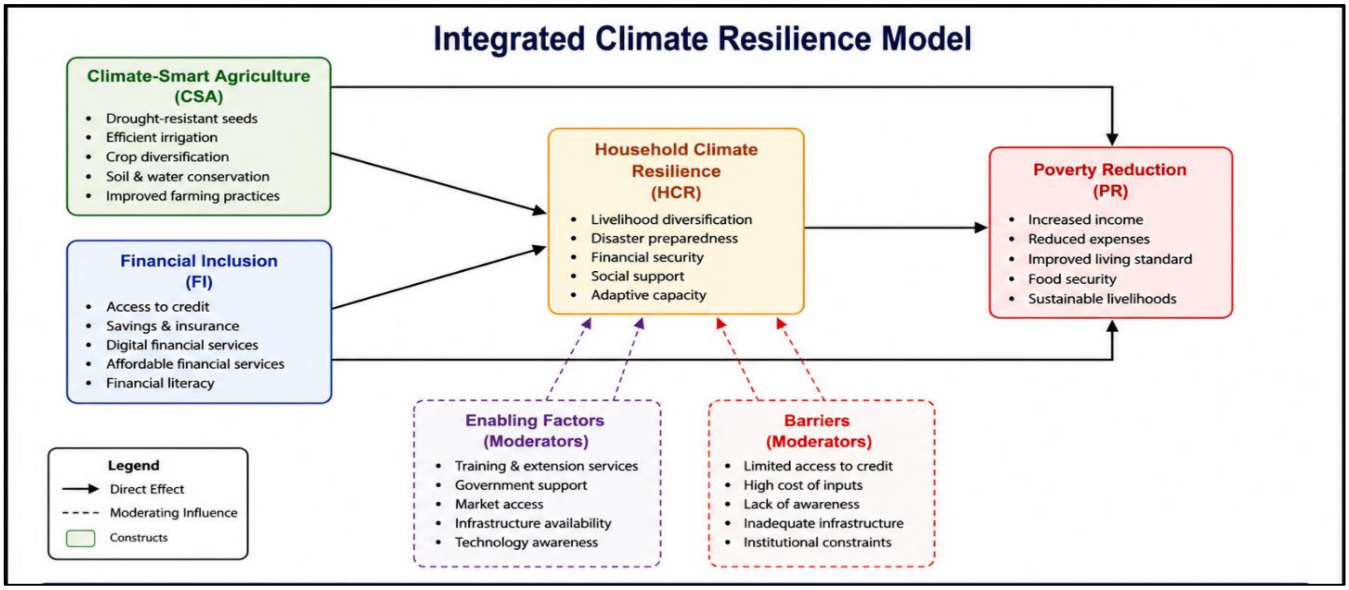
The triangulation findings reveal there was a high degree of convergence between the quantitative and qualitative findings. The statistically significant relationships, found through the use of the PLS-SEM analysis, were instead consistently supported by the persons' experiences in the interviews. The findings of the qualitative analysis also corroborated the direction of the results of the quantitative analysis and highlighted the mechanisms by which financial inclusion and climate-smart agriculture improve the resilience of households and decrease their poverty. Participants constantly insisted on the need of sustaining the farm practices, enhancing financial sources and diversifying livelihood strategies to strengthen households' ability to deal with climatic shocks and economic stability.

Moreover, insights gained by the qualitative analysis were added to the insights gained by the quantitative analysis that did not specifically focus on this particular quantitative model. Specifically, the respondents emphasized institutional support, agricultural extension and outreach, technical training, market access and policy interventions as particularly key conditions for the successful adaptation to climate change. However, poor infrastructure, lack of access to formal financial services, lack of awareness and poor government support were found to be sizable and prevailing challenges for resilience building action. These results further contribute to the further improvement of the proposed integrated climate resilience model by demonstrating the need to consider institutional and socio-economic context in addition to direct implementation of the climate-smart approaches such as the climato-correct plants and financial inclusion. In conclusion, the triangulation approach increases the credibility of the study by establishing a connection between the quantitative and qualitative results, and yields the full evidence base for policy recommendations to increase climate resilience and the target of poverty alleviation in rural communities of Sindh, Pakistan.

Interpretation of the Integrated Climate Resilience Model

The Integrated Climate Resilience Model (ICRM) depicts the linkages between various components of Climate-Smart Agriculture (CSA), Financial Inclusion (FI) and Household Climate Resilience (HCR) that shows how CSA and FI can support the reduction in poverty among rural households in Sindh, Pakistan. The quantitative results show that the adoption of Climate-Smart Agriculture and access to Financial Inclusion have a statistically significant positive impact on HCRE indicating that CSA and better access to financial resources: agricultural credit, savings, and insurance, and digital financial services increase the ability of HHs to prepare for, protect from, and recover from climate shocks. Moreover, the found direct impact of both Climate-Smart Agriculture and Financial Inclusion on Poverty Reduction indicating that better agricultural yields and financial access help to improve households' income or overall economic status and food security, on their own.

Figure 2: *Integrated Climate Resilience Model*



The qualitative findings also help informative the model by providing explanations for the statistical relationships, and also refine the model. Thematic analysis showed that achieving successful adaptation to climate change requires the implementation of climate-smart agricultural technologies or services, along with enabling conditions, including agricultural extension support, farmer training, knowledge of technologies, institutional support and access to financial services. Meanwhile, the participants pointed to lack of infrastructure, financial outflow, lack of technical skills, and a lack of institutional support among the most significant challenges to the achievement of good climate resilience. It is, therefore, observed that the integration of quantitative and qualitative evidence constitutes the main axis for linking Climate-Smart Agriculture and Financial Inclusion with Poverty reduction as well as the institutional capacity and the dissemination of knowledge further enhances the effectiveness of the relationship with Climate-Smart Agriculture and Financial Inclusion. Thus, the Integrated Climate Resilience Model offers a comprehensive approach for development practitioners and policy-makers to directly target sustainable agriculture, inclusive financial system, climate adaptation, and poverty alleviation in rural areas by addressing their combination challenges.

Implications

The results of this study have several policies, theoretical and practical implications both for the current and future advancement of climate resilience and sustainable rural development (SRD). Theoretically, it fits into the existing body of literature in the development and validation of an integrated climate resilience model, integrating Climate-Smart Agriculture, Financial Inclusion, Household Climate Resilience and Poverty Reduction under one unit. The study findings show that the linkage of quantitative evidence with qualitative aspects creates one critical pathway to link climate-smart agricultural practices and financial inclusion with the impact on enhancing rural livelihoods -- that is climate resilience in the homes of farmers. From a practical standpoint, findings offer valuable policy guidance to key actors in policy, agricultural extension services, financial service providers, and development partner organizations, highlighting the importance of multi-mission approaches to the promotion of CSFs in tandem with improved financial services, farmer-level training, digital financial inclusion, and institutional support. Better linking and strengthening of these interdependent factors can increase rural households' adaptive capacity and increase food security and speed up reaching sustainable poverty reduction in areas that are at high risk of climate change, like Sindh, Pakistan.

Limitations and Future Directions

Although the study includes substantial contributions, there are some limitations that need to be addressed. First, the quantitative analysis was a cross-sectional survey of 169 rural households that did not allow time-specific causal relationship to be made. Longitudinal research designs could be used in future research to track changes in climate resilience in response to the shifting climates. Secondly, this research was only carried out in selected rural districts of Sindh, Pakistan, which could also restrict the findings to other geographical and socioeconomic settings. The proposed model should be replicated in different provinces in Pakistan and other climate vulnerable developing countries in order to increase the external validity of the research. In addition, further factors such as effectiveness of government policy, perception of climate risk, technological innovation, social capital and institutional quality could be included in future studies to add to the understanding of the differences in household climate resilience and poverty reduction. In addition, comparative studies with different farming systems, and mixed longitudinal designs would convey deeper understandings regarding climate change adaptation strategies in a sustainable manner.

Conclusion

This study developed and validated an integrated climate resilience model which captures the contribution of Climate-Smart Agriculture and Financial Inclusion to the enhancement of Household Climate Resilience and alleviating rural poverty of the rural households in Sindh, Pakistan. The findings from the quantitative analysis confirmed the importance of coping strategies around agriculture-ecological approach and the financial inclusion in strengthening the resilience of households, explaining how these dimensions relate to the overall betterment of the household situation by a sequential explanatory mixed-methods approach that led to a better understanding of how all variables fit together to provide enhancements to the situation of people at the household level reducing poverty. The qualitative results supported these findings showing that access to institutional support, training for farmers, financial accessibility, awareness of technology, and market connectivity are vital enabling factors for successful climate adaptation, whereas poor infrastructure, access to finances, and lack of technology awareness are significant constraints. Altogether, using both quantitative and qualitative evidence gives a complete picture of climate resilience in the rural communities, and creates a solid evidence-based approach for the design of sustainable agricultural, financial and policy interventions. The case of an integrated climate resilience model is thus a useful guide for researchers, policy makers and practitioners to devising strategies for fostering long-term sustainable climate-resilient rural livelihoods and strengthening sustainable development in climate sensitive areas.

Conflict of Interest

The authors showed no conflict of interest.

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