Agric Res J **61** (5): 735-742, *October* 2024
DOI: 10.5958/2395-146X.2024.00088.5

CLIMATE-RESILIENT AGRICULTURE IN WAYANAD, KERALA: ADOPTION PATTERNS AND INFLUENCING FACTORS

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ABSTRACT

Kerala has long been prone to a variety of natural disasters, including droughts, floods, earthquakes, landslides, and rising sea levels. Among its districts, Wayanad stands out as the most vulnerable to climate variability, with significant agrarian distress. The increasing frequency and severity of weather aberrations, coupled with crop yield losses, particularly in coffee and black pepper, highlight the urgent need to understand the adoption of climate-resilient strategies by farmers in this region. Examining the level of adoption and the factors that influence it is essential for developing effective policy recommendations aimed at enhancing resilience and ensuring sustainable agricultural practices. This study focuses on coffee-growing farmers in Wayanad and identifies twenty-seven climate-resilient practices from the existing literature to assess their adoption rates. The results show that agronomic measures, such as crop diversification and soil conservation, were most widely adopted, while institutional measures, such as access to credit and market support, were less commonly implemented. Key factors influencing adoption included farm size, the experience of farmers, and the availability of institutional support. These findings provide valuable insights for policymakers seeking to improve the adoption of climate-resilient measures and enhance the adaptive capacity of farmers in Wayanad.

Key words: Agronomic measures, Coffee, Climate variability, Institutional measures

Interannual and interseasonal climate variations pose significant threats to Kerala's agricultural system, with their impacts being especially pronounced in high-altitude regions like Wayanad. This area is known for its coffee-based mixed farming systems, which are highly sensitive to fluctuations in climatic conditions (IPCC, 2014). Wayanad contributes 78.83% of Kerala's coffee-growing area and accounts for 83.52% of the state's coffee production (Coffee Board, 2023). Coffee is cultivated in the region's evergreen forest landscapes, under shaded canopies, and often intercropped with black pepper. However, the region's vulnerability to erratic and extreme weather events exposes coffee growers to considerable risks, as coffee yields are heavily dependent on specific weather patterns (Chengappa & Devika, 2016). As a climate-sensitive crop, coffee requires precise climatic conditions, including blossom showers and backing rains during the summer, which are critical for blooming and bud setting. Data from the Coffee Board indicates that in several years, these essential rains, both blossom and backing, were absent, further exacerbating the vulnerability of coffee production in the region.

In recent years, the weather patterns in Kerala have shifted, with notable disruptions in the monsoon cycle, particularly between June-July and August-September, which have had a detrimental effect on black pepper yields. Such shifts in climatic patterns, along with other extreme weather events, highlight the urgent need to enhance resilience to climate variability. The Intergovernmental Panel on Climate Change (IPCC, 2014) defines resilience to climate variability and change as the ability of a social or ecological system to absorb disturbances while maintaining its essential structure, functions, self-organization capacity, and ability to adapt to stress and change. Lokesh (2020) emphasized the importance of developing climate-resilient structures in Wayanad to enhance agricultural productivity, reduce soil erosion, improve groundwater levels, and foster broader socioeconomic development. Against this backdrop, the present study aims to assess the level of adoption of various climate-resilient practices among coffee-based farmers in Wayanad. Additionally, the study seeks to identify the key factors influencing farmers' decisions to adopt such measures, providing insights into potential strategies for building resilience in the face of ongoing climate challenges.

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Date of receipt: 03.07.2024, Date of acceptance: 22.10.2024

MATERIALS AND METHODS

The study was conducted in Wayanad, one of Kerala's high-altitude districts, which is highly vulnerable to climate variability, including floods, landslides, and droughts (GoK, 2023). The sample of respondents was randomly selected from three *panchayats* i.e. Vythiri (AEU No. 15), Ambalavayal (AEU No. 20), and Noolpuzha (AEU No. 21), representing three distinct agro-ecological units (AEUs) within the district. Kerala is divided into 23 AEUs, based on its diverse agro-ecological conditions (KAU, 2016). Forty farmers were randomly chosen from each AEU, resulting in a total sample size of 120 farmers. The study primarily focused on coffee-based farming systems, as coffee occupies 33.65% of the total cropped area in Wayanad, covering 67,426 hectares (GoK, n.d.). Due to its substantial land coverage, coffee plays a pivotal role in the agricultural economy of the region.

The extent of farmers' adoption of climate-resilient technologies was assessed using a structured schedule comprising 27 adaptation strategies. These strategies were categorized into soil and water conservation, agronomic practices, and institutional measures. The selected practices were identified through a review of existing literature and consultations with experts. To evaluate the adoption levels, a three-point continuum or scoring pattern was employed, which allowed for the assessment of different degrees of adoption of climate-resilient practices by each farmer. The scoring pattern used is as follows:

Table 1. Scoring pattern for adoption of climate-resilient practices

Particular	Scores/ Weights
Adopted	3
Partially adopted	2
Not adopted	1

The frequencies of their responses were then used to calculate weighted scores, indicating the significance attributed to each technique or strategy and the relative importance of various categories of practices.

The adoption index of each individual farmer was calculated using the given formula:

$$\text{Adoption index} = \frac{[\text{Respondent total score}]}{[\text{Total possible score}]} \times 100$$

Using the calculated adoption index for individual farmers, the factors influencing the adoption of climate-resilient technologies were analyzed through logistic regression. Logistic regression, whether univariate or multivariate, estimates the probability of an event occurring by predicting a binary dependent outcome based on independent variables. In this study, the adoption index served as the binary dependent variable. To convert the adoption index into binary form, participants were divided into two groups: those with an adoption index exceeding 65.35, indicating a high adoption rate, and those with an index below this threshold, indicating a low adoption rate. This threshold was determined by calculating the mean adoption index of the 120 farmers in the sample. The model is represented as:

$$P_i = E(Y = 1|X_i) = \frac{1}{1 + e^{-(\alpha + \beta_i X_i)}} = \frac{1}{1 + e^{-Z_i}}$$

where,

P_i is the probability

X_i is the vector of independent variable

β_i s are the coefficients to be estimated

$$Z_i = \alpha + \beta_i X_i$$

$$1 - P_i = 1 - \frac{1}{1 + e^{-Z_i}}$$

$$= \frac{1 + e^{-Z_i} - 1}{1 + e^{-Z_i}} = \frac{e^{-Z_i}}{1 + e^{-Z_i}}$$

$$\frac{P_i}{1 - P_i} = \frac{\frac{1}{(1 + e^{-Z_i})}}{\frac{e^{-Z_i}}{(1 + e^{-Z_i})}} = \frac{1}{e^{-Z_i}}$$

$$\frac{P_i}{1 - P_i} = e^{Z_i}$$

Taking logarithm on both sides,

$$L_i = ln\left(\frac{P_i}{1 - P_i}\right) = Z_i$$

L_i is called the logit

Details of dependent variable and independent variable are provided in Table 2.

RESULTS AND DISCUSSION

Socio-demographic profile of sample farmers

The general characteristics of the surveyed farmers, as outlined in Table 3, provide a comprehensive overview of their demographic and economic profiles. A significant proportion of the farmers, 36.7%, fall within the age range of 50 to 59 years, with the average age being 58 years. This indicates that many farmers are relatively older, bringing a wealth of experience to their agricultural practices. In fact, 54.16% of the farmers have more than 30 years of farming experience, with the average number of years worked in farming being 35, highlighting a positive correlation between age and experience. Regarding education, 46.67% of the farmers have completed high school or higher secondary education, reflecting a reasonable level of

Table 2. Description of dependent and independent variables

Sr. No.	Particular	Unit
1.	Education level of the farmer (X_1)	Number of years of schooling
2.	Farm size (X_2)	Hectare
3.	Experience in farming (X_3)	Number of years of experience in farming
4.	Age of the respondent (X_4)	Number of years
5.	Annual income (Household income) (X_5)	Rupees
6.	Institutional support (X_6)	0 – Not accessed any institutional support 1 – Accessed institutional support
7.	Exposure to training (X_7)	0 – Not attended any training programs 1 – Attended training programs
8.	Dependent variable (Y)	0 – Lower adoption index 1 – Higher adoption index

literacy within the sample. In terms of landholding, the majority (68.33%) are classified as marginal farmers, owning less than one hectare of land, with the average operational landholding being 0.8 hectares. This highlights the challenges faced by many farmers who operate on small-scale farms. Despite this, 70% of the farmers rely on farming as their primary source of livelihood. When it comes to income, more than a quarter (34.16%) earn between ₹1 lakh and ₹2 lakh annually, with the average income standing at ₹2,56,000. Finally, 75.83% of the farmers have a family size ranging from four to six members, with an average family size of four, which is typical for rural households. These characteristics highlight the complexities faced by farmers, balancing aging, limited land resources, and moderate income levels, while heavily depending on agriculture as their main source of livelihood.

Adoption of climate-resilient farming practices

Climate resilience refers to the capacity to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate (C2ES, 2019). To assess the extent of adoption of various climate-resilient technologies, we identified 27 technologies categorized into soil and water conservation measures (8 practices), agronomic measures (15 practices), and institutional measures (4 practices). Responses were collected from 120 farmers, indicating whether they fully adopted, partially adopted, or did not adopt each practice. To quantify the adoption levels, the weighted adoption score for each practice, as well as the category-wise weighted mean, were calculated and are presented in Table 4. The weighted adoption score for each practice was determined by multiplying the number of farmers in each adoption category (fully adopted, partially adopted, not adopted) by their respective scores (3, 2, and 1, respectively), and then dividing the sum by 360. The denominator value of 360 represents the total possible score for a practice if all 120 farmers fully adopted it. In this context, the scores are used as weights. Similarly, the category-wise adoption score was derived by calculating the mean value of the weighted adoption scores across the practices in each category.

Soil and water conservation measures

Among the respondents surveyed, only 32% of farmers utilized irrigation systems. The low adoption rate of irrigation structures was primarily attributed to the high initial investment costs and concerns about water availability during the summer. Thirteen percent of farmers relied on farm ponds for irrigation, while others used tube wells or open wells. Micro-

Table 3. Socio-demographic profile of sample farmers

Particular	Average	Most of the sample farmers belongs to
Age	58 years	50-59 (36.7%)
Education		High school and higher secondary education (46.67%)
Experience in farming	35 years	>30 years (54.16%)
Land holding pattern	0.8 hectare	<1 hectare (68.33%)
Occupation		Agriculture (70%)
Annual income	Rs. 2,56,000	Rs.1 - 2 lakhs (34.16%)
Family size	4 (number)	4-6 (75.83%)

Table 4. Adoption of climate-resilient farming practices

Sr. No.	Climate resilient technologies	Frequency (N=120)			Weighted adoption score	Category wise weighted mean
		Adopted	Partly adopted	Not adopted		
Soil and Water conservation measures						
1.	Digging and maintaining farm ponds	16 (13.33)	0 (0.00)	104 (86.67)	**42.22**	**58.41**
2.	Micro irrigation	14 (11.67)	1 (0.83)	105 (87.5)	**41.39**	
3.	Rainwater harvesting	120 (100)	0 (0.00)	0 (0.00)	**100.00**	
4.	Construction of check dam	9 (7.5)	5 (4.17)	106 (88.33)	**39.72**	
5.	Cover cropping	20 (16.67)	15 (12.5)	85 (70.83)	**14.58**	
6.	Organic matter addition	116 (96.67)	3 (2.5)	1 (0.83)	**98.61**	
7.	Live bunds/fence	53 (44.17)	29 (24.17)	38 (31.66)	**70.83**	
8.	Terracing	30 (25.00)	36 (30.00)	54 (45.00)	**60.00**	
Agronomic practices						
9.	Soil test-based fertilizer application	7 (5.83)	10 (8.33)	103 (85.84)	**40.00**	**69.41**
10.	Pest and disease resistant varieties	0 (0.00)	120 (100)	0 (0.00)	**66.67**	
11.	Drought tolerant varieties	9 (7.50)	13 (10.83)	98 (81.67)	**41.94**	
12.	Agroforestry	120 (100)	0 (0.00)	0 (0.00)	**100.00**	
13.	IFS approach	31 (25.83)	13 (10.83)	76 (63.34)	**54.17**	
14.	Establishing shade trees	120 (100)	0 (0.00)	0 (0.00)	**100.00**	
15.	Alteration in fertilizer and pesticide usage	71 (59.16)	49 (40.84)	0 (0.00)	**86.39**	
16.	INM practices	111 (92.50)	7 (5.84)	2 (1.66)	**96.94**	
17.	IWM practices	4 (3.33)	116 (96.67)	0 (0.00)	**67.78**	
18.	HY and drought resistant forage crops	2 (1.67)	3 (2.5)	115 (95.83)	**35.28**	
19.	Use of suitable breeds/var. for climate	0 (0.00)	120 (100)	0 (0.00)	**66.67**	
20.	Mixed farming	120 (100)	0 (0.00)	0 (0.00)	**100.00**	
21.	Multi-tier cropping	120 (100)	0 (0.00)	0 (0.00)	**100.00**	
22.	Shifting to organic farming	3 (2.5)	53 (44.16)	64 (53.34)	**49.72**	
23.	Fertigation	3 (2.5)	2 (1.67)	115 (95.83)	**35.56**	
Institutional measures						
24.	Weather insurance	2 (1.66)	5 (4.17)	113 (94.17)	**35.83**	**50.62**
25.	Supply management through market and non-market intervention	34 (28.33)	6 (5.00)	80 (66.67)	**53.89**	
26.	Irrigation schedule based on weather forecasting	7 (5.83)	0 (0)	113 (94.17)	**37.22**	
27.	Custom hiring centers	53 (44.17)	46 (38.33)	21 (17.50)	**75.56**	

irrigation technologies, such as sprinkler systems, were fully adopted by 12% of farmers, with less than 1% partially adopting them. Drip irrigation, another form of micro-irrigation, was not widely adopted on coffee-based farms, largely due to the region's undulating topography. All farmers, however, had constructed rainwater harvesting structures, typically earthen pits. Check dams, designed to retain flowing water for irrigation, were fully adopted by 8% of farmers and partially adopted by 5% of respondents. Traditionally, farmers built temporary check dams using sacks filled with soil. In response to the devastating floods of 2018, the government of Kerala initiated the construction of permanent check dams in two rivers-Ambalavayal-Nellarachal and Vythiri-Kunnathidavaka. These permanent check dams help replenish groundwater levels in nearby households during the summer months.

Approximately 17% of farmers adopted cover cropping during the establishment phase as a cost-effective strategy to suppress weed growth and improve soil nutrient levels. This practice also helps alleviate the financial burden associated with weed management in the early stages of coffee cultivation. Farmers primarily use legumes as cover crops, which enhance soil fertility. Nearly 97% of farmers incorporate organic matter into their soils, a crucial practice for improving soil structure and biology, thereby promoting long-term soil productivity (Montgomery, 2017). This improvement enhances water retention, controls erosion, and supports resilient microbial ecosystems. Forty-four percent of farmers fully adopted live fences to mitigate soil erosion, while 24% partially adopted them. In Vythiri, some farmers along riverbanks cultivate bamboo as live fences due to its robust root system, which helps prevent erosion and acts as a windbreak. Among coffee farmers, popular choices for live fences include hibiscus and gliricidia, both of which also provide green leaf manure, with gliricidia being especially valued for this purpose. The enduring nature of hibiscus plants has made them a cost-effective option for many farmers over the years.

Terracing was employed on slopes, with 25% of farmers fully adopting it and 30% implementing it selectively on the steeper sections of their farms. Among the eight soil and water conservation measures, the addition of organic matter and rainwater harvesting showed the highest adoption rates. In contrast, the adoption rates for farm pond excavation, cover crop cultivation, and micro-irrigation techniques were lower. The incorporation of organic matter into coffee cultivation is a traditional practice, which likely contributes to its continued high adoption rate among farmers. Most of the surveyed farmers were marginal, with some owning less than an acre of land (0.4 hectares). Given the limited space available, smaller and medium-sized farmers tend to prefer constructing farm ponds over adopting micro-irrigation systems, which require higher financial investment.

Agronomic measures

All farmers are aware of the recommended practice of applying fertilizers after soil testing to address nutrient deficiencies; however, the adoption rate of this practice remains low, with only 6% of farmers implementing it. Similarly, all farmers have partially adopted pest- and disease-resistant varieties. While Arabica coffee was traditionally cultivated in the region, farmers have transitioned to Robusta coffee due to the former's unsuitability for the Wayanad climate and its susceptibility to white stem borer. In black pepper cultivation, farmers have adopted Phytophthora foot rot-resistant varieties, although their effectiveness remains uncertain. The adoption of drought-resistant varieties, particularly the Kalluvally variety of black pepper, was notably low, with only 8% of farmers opting for it. However, all surveyed farmers engage in practices such as establishing shade trees, agroforestry systems, mixed farming, and multitier cropping. Commonly used shade plants include Silver oak, Jackfruit, *Swietenia macrophylla*, and *Erythrina* spp. These plants help mitigate temperature fluctuations and reduce transpiration losses, thus regulating the microclimate. Previous studies have shown that shade trees can reduce coffee leaf temperatures by up to 4°C under suboptimal hot conditions (Vaast *et al.*, 2004). Additionally, shade contributes to cooler soil temperatures, fostering microbial and mycorrhizal activity, which enhances nutrient uptake, improves plant health, and may increase yields (Montgomery, 2017). Integrated Nutrient Management (INM), which combines organic manures and inorganic fertilizers, demonstrated high adoption rates in the study area. Approximately 93% of farmers fully adopted INM practices, while 6% partially adopted them. In contrast, Integrated Weed Management (IWM) practices had a very low adoption rate of only 3%, possibly due to insufficient awareness of IWM practices.

The cultivation of forage crops, the application of fertilizers through irrigation water (fertigation), and organic farming had the lowest adoption rates, at 2%, 3%, and 3%, respectively. Forage crops were primarily grown in fallow paddy fields for livestock feed. A significant proportion of farmers were involved in various forms of organic cultivation, with 44% adopting it partially. However, only a small fraction (3%) had fully transitioned to complete organic farming practices. Among the 15 agronomic measures considered, the establishment of shade trees, mixed farming, multitier cropping systems, and agroforestry systems exhibited the highest adoption rates. In contrast, the cultivation of forage crops and the use of fertigation had the lowest adoption rates. Coffee has traditionally been cultivated in evergreen forest settings under a shaded canopy, which has led to a 100% adoption rate of agroforestry systems and shade tree planting among farmers.

Institutional measures

Despite the presence of institutions like the Coffee Board and various NGOs dedicated to supporting coffee growers, the adoption of institutional measures remained relatively low. Government outreach for other crops, such as black pepper and arecanut, typically occurs through *Krishibhavans* (Panchayat-level Agricultural Offices). Only 2% of farmers adopted weather insurance schemes, with an additional 4% partially adopting them. Weather insurance is primarily used for crops like rice and banana. Most respondents were unaware of the Rainfall Insurance Scheme for Coffee (RISC), offered by the Coffee Board in collaboration with the Government of India, with the exception of a single farmer. This lack of awareness aligns with observations made by Karunakaran (2017), who also highlighted the need for more coffee growers to take advantage of the benefits provided by the Coffee Board. Farmers who were registered with local NGOs, such as WSSS and Perfetto Naturals, reported better access to markets for their coffee, often at improved prices. Approximately 28% of farmers benefited from such organizations in marketing their produce, indicating the positive role that these institutions play in enhancing market access and pricing for coffee growers.

Although 32% of farmers have access to irrigation facilities, only a small proportion (6%) practiced scheduled irrigation based on weather forecasting. Most farmers relied on observed weather variations to decide when to irrigate their fields. Among institutional measures, the adoption rate of custom hiring centres was relatively higher, with approximately 45% of farmers frequently hiring machinery from these centres, and an additional 38% using the services occasionally. In contrast, weather insurance had the lowest adoption rate among the institutional measures. Given the increasing frequency of weather anomalies, the low adoption rate of weather insurance remains a significant concern for enhancing resilience among farmers.

Category-wise adoption of climate resilient technologies

The weighted adoption score for each practice was calculated, and the category-wise weighted mean was determined based on the frequency of adoption. From Table 3, it is evident that agronomic measures were the most adopted, while institutional measures were the least adopted. The weighted mean for the adoption of soil and water conservation, agronomic, and institutional measures was 58.41, 69.41, and 50.62, respectively.

Factors influencing adoption of climate resilient practices

Several factors influenced the adoption of climate-resilient farming practices. A logistic regression analysis assessed the relative importance and significance of each factor. Each farmer's adoption index, converted into binary form (0 or 1), was regressed against eight selected independent variables. These variables were chosen based on previous studies. Before conducting logistic regression, multicollinearity among the selected variables was assessed, and the Variance Inflation Factor (VIF) was found to be below 10, indicating no significant multicollinearity issues. The results of the logistic regression analysis are presented in Table 4.

Among the factors analyzed, farm size, farmers' experience, and institutional support emerged as significant contributors to the adoption of climate-resilient technologies, with all three factors being statistically significant at the 5% level. For each unit increase in farm size, the odds of adopting resilient measures increase by 1.52, or 52.3%. Similarly, an increase in institutional support results in a 2.42-fold increase in the likelihood of adopting resilient measures, representing a 142.2%

Table 5. Factors influencing adoption of climate resilient practices

Sr. No.	Particulars	Estimate	*P* value	Odds ratio
1.	Constant	-3.07	0.180	0.05
2.	Education	0.037	0.696	1.04
3.	Farm size	0.421*	0.046	1.52
4.	Experience	0.060*	0.035	1.06
5.	Age	-0.313	0.406	0.97
6.	Annual income	-0.00000049	0.721	1.00
7.	Institutional support	0.884*	0.012	2.42
8.	Exposure to training	0.096	0.087	2.60
McFadden R^2: 0.24				

*indicates $p<0.05$

increase. Additionally, for each unit increase in farming experience, the odds of adopting resilient measures increase by 1.06, or 6.2%. These results suggest that larger farm sizes, greater institutional support, and more years of farming experience significantly encourage farmers to adopt climate-resilient practices. Furthermore, they highlight the influence of socio-economic factors on decision-making at the farm level.

Anseera (2019) conducted a correlation analysis of various socio-economic factors in relation to the adoption of climate-resilient technologies, finding that education, farm size, annual income, and innovativeness were significantly correlated with the adoption of these technologies. Similarly, Noorhosseini-Niyaki and Allahyari (2012) performed a logistic regression analysis on factors influencing the adoption of rice-fish farming, identifying family size, institutional support, and contact with extension agents as significant determinants.

The education level of farmers was found to be an insignificant factor in the adoption of climate-resilient technologies. Regardless of their educational background, most farmers in the study region have embraced technologies such as multi-tier cropping systems and rainwater harvesting structures. The adoption of these technologies appears to be more influenced by practical farming experience rather than formal education. Notably, non-governmental organizations (NGOs) have played a crucial role in encouraging the adoption of these practices among less educated farmers. However, education does play a more significant role in the adoption of certain activities, such as soil testing, micro-irrigation techniques, and fertigation, all of which had relatively low adoption rates.

We anticipated that family income would have a positive influence on farmers' climate resilience. However, the results revealed that annual income did not significantly influence the adoption of climate-resilient practices. The majority of respondents reported an annual income between one lakh and two lakhs, with an average family size of four. Given this income level and family size, farmers may face challenges in making the financial commitments required to implement measures that mitigate climate vulnerability.

Traditional goodness-of-fit measures, such as R^2, are not particularly meaningful in binary regression models. Instead, pseudo R^2 measures are used, with several variations available. One such measure is McFadden's R^2, denoted as R^2_{MCF}, which typically ranges from 0 to 1. In the present model, the McFadden R^2 value is 0.24. It is important to note that in binary regression models, the emphasis is less on the goodness of fit and more on the expected signs of the regression coefficients, as well as their statistical and practical significance (Gujarati, 2003).

CONCLUSION

Given the significant climate variability in high-altitude regions, the adoption of climate-resilient measures is critical for plantation farmers. This study focuses on the adoption of such measures among coffee farmers in Wayanad, a highly vulnerable district in Kerala. The findings indicate a higher adoption rate for various agronomic measures, while institutional measures have been adopted to a lesser extent. Robusta coffee, which relies on summer showers for blooming and bud set, is particularly sensitive to climatic conditions, directly affecting yield and profitability. Despite the scarcity of summer showers in February and March, adoption rates for micro-irrigation techniques and farm pond maintenance were found to be low. Understanding the factors that hinder or promote the adoption of climate-resilient measures is crucial for formulating effective policy recommendations. The logistic regression model developed in this study shows that farm size, institutional support, and farmers' experience significantly influence adoption rates. Although institutional measures have a lower adoption rate, the model highlights the importance of institutional support in encouraging adoption, highlighting the need to strengthen such support to effectively implement climate-resilient technologies among farmers.

Since farmers' experience was identified as a key factor in adopting climate-resilient practices, promoting their participation in farmer groups or cooperatives could provide a valuable platform for knowledge-sharing. Such collective forums would enable farmers to exchange experiences and collaborate on investing in climate-resilient technologies. Future research should focus on monitoring the long-term impacts of adopting these technologies, exploring region-specific water management strategies for more efficient methods, and identifying policy gaps to advocate for stronger support for smallholder farmers in implementing these practices.

Authors' contribution

Conceptualization and designing of the research work (AAC, HM, AP, DF, SJ); Data collection (AAC); Analysis of data and interpretation (AAC, HM, DF); Preparation of manuscript (AAC, HM).

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