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[Michel Rwema](#)*, [Bonfils Safari](#), [Mouhamadou Bamba Sylla](#), Lassi Roininen, [Marko Laine](#)

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Article

Understanding Farmers' Knowledge, Perceptions, and Adaptation Strategies to Climate Change in Eastern Rwanda

Michel Rwema ^{1,*}, Bonfils Safari ², Mouhamadou Bamba Sylla ², Lassi Roininen ² and Marko Laine ²

¹ African Institute for Mathematical Sciences, Research and Innovation Centre, Kigali, Rwanda

² School of Science, College of Science and Technology, University of Rwanda, Kigali, Rwanda

³ Lappeenranta-Lahti University of Technology, Lappeenranta, Finland

⁴ Finnish Meteorological Institute, Helsinki, Finland

* Correspondence: michel@aims-cameroon.org

Abstract: This study investigates farmers' knowledge, perceptions, and adaptation strategies to climate change in Rwanda's Eastern Province, integrating social and physical science approaches. Analysing meteorological data (1981-2021) and surveys from 204 farmers across five districts, we assessed climate trends and adaptation behaviors using statistical methods (descriptive statistics, Chi-square, logistic regression, Regional Kendall test, dynamic linear state-space model). Results show that 85% of farmers acknowledge climate change, with 54% observing temperature increases and 37% noting rainfall declines. Climate data confirm significant rises in annual minimum (+2.95°C) and mean temperatures (+1.87°C), with the largest seasonal increase (+3.37°C) in June-August. Rainfall trends indicate a non-significant decrease in March-May and a slight increase in September-December. Farmers report crop failures, yield reductions, and food shortages as major climate impacts. Common adaptations include agroforestry, crop diversification, and fertilizer use, though financial limitations, information gaps, and input scarcity impede adoption. Despite limited formal education (53.9% primary, 22.3% no formal education), indigenous knowledge aids seasonal prediction. Livestock ownership, group membership, and climate data access are key adaptation enablers. These findings emphasize the need for targeted policies and climate communication to enhance rural resilience by strengthening smallholder farmer support systems for effective climate adaptation.

Keywords: climate change; climate trends; farmer perception; adaptation strategies; small holder farmers; Eastern Rwanda

1. Introduction

Increasing greenhouse gases in the earth's atmosphere owing to human activities such as the burning of fossil fuels and deforestation together with natural activities since the mid-20th century, resulted in a global average temperature increase [1–3]. The rise in the earth's temperature, known as global warming, influences climate and weather patterns from global to local scales. The existing consequences of climate change that have been identified include frequent and intense droughts, downpours, floods, hurricanes, storms, water scarcity, severe wildfires, melting polar ice, sea level rise, and declining biodiversity [4]. Those consequences have hit most of the critical sectors of life, ranging from agriculture, food production, water resources, energy, health and public health systems, transportation, infrastructure, ecosystems, and biodiversity [5].

People worldwide experience climate change impacts in various ways, with varying severity based on geographic location and primary economic activities. Agriculture remains a crucial sector

supporting a significant portion of the population in Africa, a continent with many developing nations. Most agricultural activities are rain-dependent, increasing their vulnerability to climate change effects [6,7]. Changes in temperature and rainfall patterns owing to climate change have posed significant challenges for agricultural communities across the African continent, with the severity of these challenges varying from region to region and country to country.

In East Africa, many people in this region, especially those in agriculture sector, are impacted by climate change through protracted droughts, floodings, and water scarcity, which put them at risk of food insecurity [8]. Rwanda, one of the East African nations, has been previously studied, revealing changes in temperature and rainfall during important seasons over the years. These changes include the observed decline in seasonal and annual total rainfall [9–12] and increasing temperature [13–15] in many parts of the country. Rwanda's Eastern Province, which is the largest under agricultural production, studies including Sebaziga et al. [11] and Rwema et al. [16] noted a decrease in seasonal rainfall while a high increase in temperature was also recorded over this region [17].

Increased temperatures and decreased rainfall often resulted in diminished water availability for rainfed agriculture, increasing the likelihood of droughts and intensifying pressure on agricultural water resources [18,19]. Over the past few decades, Eastern Rwanda has faced recurring deficits in rainfall, resulting in severe and prolonged droughts. Consequently, water scarcity and food insecurity have escalated in this area [20,21], leading to diverse experiences among farmers.

Repeated exposure to climate-related hazards influences individuals' perceptions [22], prompting the development of various adaptation and mitigation strategies to address the perceived impacts. Factors including knowledge, beliefs, and perceptions play a crucial role in developing and adopting adaptation strategies. It is imperative to understand climate change comprehensively by exploring its physical mechanism and considering individual behaviors in response to the occurring changes.

Previous studies conducted in Eastern Rwanda have predominantly centered on climatic mechanisms, particularly analysing trends and variabilities in annual and seasonal temperature and rainfall patterns [9,11,16]. Studying the climate aspect is very important for several reasons: it promotes a better understanding of patterns and dynamics of climate systems. It also reveals long-term trends in climate variables, which further explain significant implications for vital sectors such as agriculture, water resources, and health. Furthermore, analysing historical data enables the construction of models and projections for future climate conditions, which is crucial for decision-makers to take appropriate actions to adapt to and mitigate the potential impact of climate change. However, very little attention has been put into exploring the variations in behaviors among individuals, particularly farmers, concerning their perceptions, experiences, and knowledge of climate change across the Eastern Province. This information helps identify the knowledge gaps and misconceptions, allowing for tailored educational efforts [23] in vulnerable communities.

Studying how individuals perceive and experience climate change is also instrumental in assessing their behavioral responses and identifying barriers to adaptation and sustainable behaviours [24]. Additionally, engaging with local and indigenous knowledge provides valuable insights into climate change impacts at local and regional levels. This knowledge complements historical data, informs policy decisions, and contributes to more context-specific responses.

This study aims to explore farmers' knowledge and perceptions of climate change, its impacts, and the adaptation strategies employed in the Eastern Province. Additionally, it seeks to identify the factors that influence farmers' decisions to adopt specific adaptation measures. To accomplish this, we analysed data gathered from interviews with farmers across five districts in Eastern Rwanda.

The remaining part of this manuscript is structured as follows: the second section gives details of the methods used for data collection and analysis in the study. The third section presents the findings, which are discussed further in the fourth section. Lastly, the fifth section provides conclusions and offers recommendations.

2. Materials and Methods

2.1. Study Area

This study is conducted in the Eastern Province of Rwanda, the largest (9813000000 m²) of the five provinces. Its administrative borders connect this province to three countries: Uganda to the North, Tanzania to the East, and Burundi to the South. It is subdivided into seven districts: Bugesera, Gatsibo, Kayanza, Kirehe, Ngoma, Nyagatare, and Rwamagana (see Figure 1). Geographically, the Eastern Province is located approximately between longitudes 29.9° and 30.9° E and latitudes 1.1° and 2.3° S. The region's topography features lowland areas with altitudes below 1,500 m, characterized by a high annual mean temperature exceeding 293.15 K and low annual rainfall of less than 1,000 mm. With the largest population (i.e., 3,563,145), the region's economy mainly relies on agriculture and livestock. The Eastern region experiences four seasons throughout the year, including two rainy seasons and two dry seasons. The primary rainy seasons occur from March to May (MAM) and from September to December (SOND), with April and November serving as the peak months for these seasons, respectively. Conversely, the dry seasons take place from January to February (JF) and from June to August [25]. Most agricultural practices in this area rely on rainfall and align with the two rainy seasons [26,27]. The main crops in Eastern Rwanda include maize, beans, sorghum, rice, cassava, and bananas. As in other parts of the country, the high dependence on rainfall increases vulnerability to the adverse impacts of changes and variability in rainfall and temperature [18,19]. Over the past few decades, drought has emerged as a significant challenge in this region, leading to decreased agricultural and livestock production, exacerbating food insecurity among a substantial portion of the population [20,21]. From the Northern to the Southern regions of the Eastern Province, farmers have extensive insights to share, particularly about climate change, its impacts, and various adaptation strategies. The farmers participating in this study were recruited from five of the seven districts in the Eastern Province: Nyagatare, Gatsibo, Kayanza, Ngoma, and Kirehe (see Figure 1).

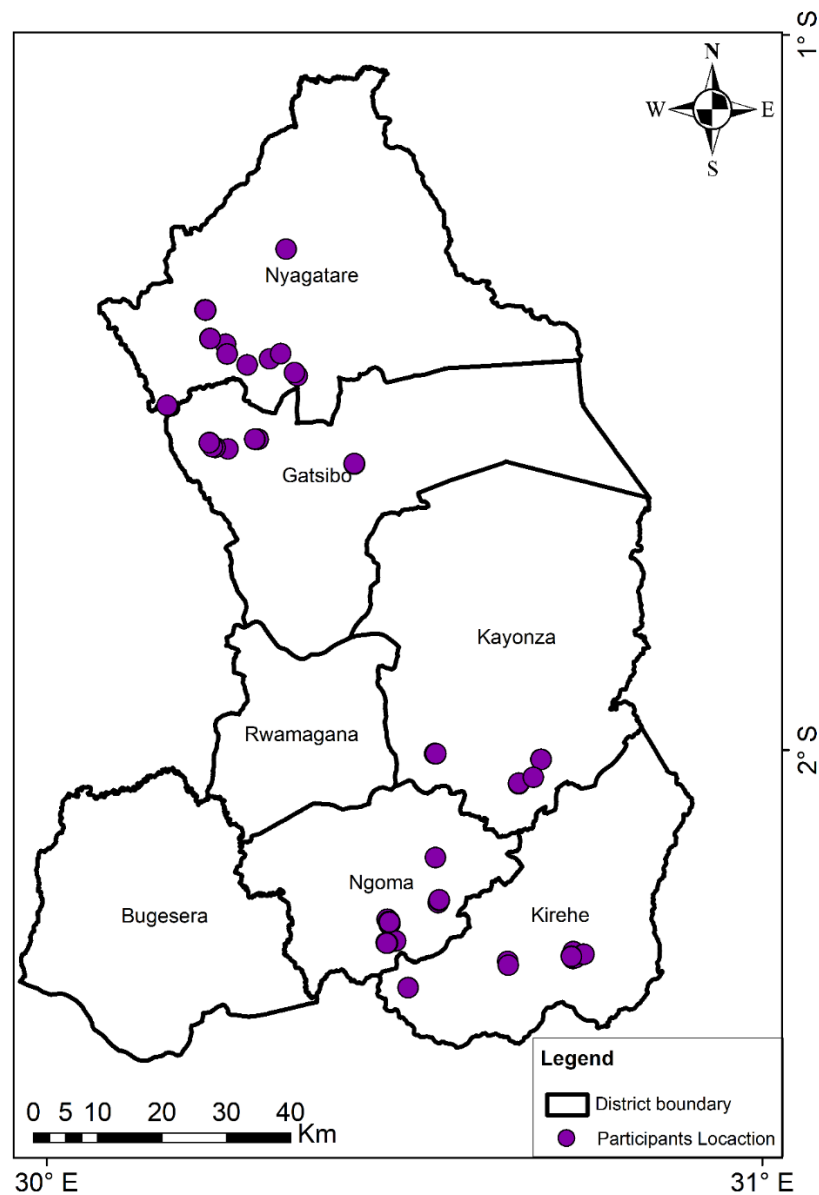


Figure 1. Eastern Province map with the surveyed participants’ location highlighted with purple dots.

2.2. Sample (s)

The total number of 638,806 agricultural households from seven districts of the Eastern Province [28] was considered to be the population size. With Yamane’s formula [29], we estimated the size of the sample to be 204 heads of households at a 93% confidence level, which implies allowing a margin error of 7%.

$$n = \frac{N}{(1+Ne^2)}, \tag{1}$$

where n = Sample size, N = Total population, and e = Margin of error.

Multistage sampling was used to select respondent farmers from the Eastern Province. Five of the seven districts in the Eastern Province were chosen purposely to ensure representation from the North, Central, and Southern regions. In the North, we included Nyagatare and Gatsibo districts; in the Central area, we included Kayonza district; and in the South, we included Ngoma and Kirehe districts (See Figure 1.). Sectors from each district were selected systematically, mainly based on agriculture activities, farmers’ availability, and accessibility. From each sector, with the assistance of sector agronomists, we purposely selected cells based on farmers’ availability. In each cell, the Executive Secretary or Socio-Economic Development Officer (SEDO) helped identify exemplar

farmers who randomly helped select their fellow farmers. The distribution of respondent farmers from the districts to cells, as shown in Table 1., indicates the number of respondent farmers per district as follows: Nyagatare (33), Gatsibo (35), Kayonza (36), Ngoma (74), and Kirehe (26).

Table 1. Farmers’ distribution in districts, sectors, and cells.

<i>Zone</i>	<i>District</i>	<i>Sector</i>	<i>Cell</i>
<i>North</i>	<i>Nyagatare (33)</i>	<i>Nyagatare (1)</i>	<i>Nyagatare (1)</i>
		<i>Gatunda (9)</i>	<i>Nyamirembe (9)</i>
		<i>Mukama (6)</i>	<i>Gihengeri (1), Rugarama (5)</i>
		<i>Mimuri (4)</i>	<i>Mimuri (2), Rugari (2)</i>
		<i>Katabagemu (13)</i>	<i>Barija (3), Nyakigando (9), Ryaruganzu (1)</i>
	<i>Gatsibo (35)</i>	<i>Ngarama (10)</i>	<i>Nyarubungo (9), Cyigashi (1)</i>
<i>Central</i>	<i>Kayonza (36)</i>	<i>Nyagihanga (14)</i>	<i>Gitinda (14)</i>
		<i>Kabarore (11)</i>	<i>Nyabikiri (10), Nyabikenke (1)</i>
		<i>Ndego (10)</i>	<i>Byimana (7), Kiyovu (3)</i>
		<i>Kabare (12)</i>	<i>Rubumba (10), Cyarubare (1), Karubimba (1)</i>
		<i>Kabarondo (14)</i>	<i>Cyabajwa (14)</i>
	<i>South</i>	<i>Ngoma (74)</i>	<i>Mutenderi (24)</i>
<i>Kazo (29)</i>			<i>Kinyonzo (29)</i>
<i>Murama (21)</i>			<i>Sakara (19), Rurenge (1), Mvumba (1)</i>
<i>Kirehe (26)</i>		<i>Nyamugali (10)</i>	<i>Nyamugali (7), Kiyanzi (3)</i>
		<i>Kigina (11)</i>	<i>Gatarama (11)</i>
		<i>Musaza (5)</i>	<i>Mubuga (4), Nganda (1)</i>

2.3. Data Type and Data Collection Approach

The meteorological data analysed included rainfall through derived seasonal rainfall variables such as seasonal rainfall amount, onset and cessation, and seasonal duration, along with minimum, maximum, and average temperatures at both annual and seasonal levels. The rainfall and temperature datasets were obtained from the Rwanda Meteorology Agency (Meteo Rwanda) [30]. The farmers’ data were based on recorded responses from interviews conducted in November 2023 with farmers from the Eastern Province of Rwanda. A semi-structured questionnaire featuring both open and closed questions was prepared and used for data collection. The information gathered can be categorised into five main sections. The first section targeted the socioeconomic characteristics of the participants; section two examined knowledge of weather and climate change; section three focused on farmers’ perceptions regarding climate change and its impacts. In section four, we explored farmers’ adaptation strategies, while section five addressed barriers to adaptation. Using the Open Data Kit (ODK) [31], the questionnaire was refined and incorporated into smartphones and tablets for use during field interviews with the data collectors. We applied an in-depth interview technique involving intensive individual interviews with 204 farmers from the Eastern Province. Depending on the respondent’s understanding, the interview lasted between 3,600 and 5,400 seconds. Farmers involved in the survey verbally agreed, expressing their readiness to participate in our interviews.

2.4. Data Analysis

2.4.1. Climate Data Analysis

To analyze rainfall events, we applied the non-parametric Regional Kendall test [32]. This test enhances the Mann-Kendall test [33,34] by enabling the simultaneous analysis of trends across multiple locations while accounting for spatial correlation among datasets. It is robust against non-

normal distributions and is less influenced by missing data and outliers [35]. This enhanced capacity allows for the identification of region-wide patterns and trends, considering the interrelationships among different monitoring stations or regions. The Regional Kendall test has been widely employed to determine whether there is an increasing or decreasing trend over time in environmental and climatic data [36–38]. The magnitude of the trend was quantified using the non-parametric Sen's Slope estimator, which is reliable and resistant to the influence of outliers [11,16,39]. Seasonal and annual changes in minimum, maximum, and mean temperatures are calculated using a dynamic linear state-space model. This model effectively captures overall changes and temporal patterns by connecting hidden states that evolve over time to observed measurements while accounting for random fluctuations [40–43]. The construction procedure for a DLM model and estimations of model states and parameters can be found in Rwema et al. [44], which utilizes a similar DLM model to investigate trends in air temperature across nearly homogeneous zones of the Eastern Province of Rwanda.

2.4.2. Farmers' Field Data Analysis

After collecting field data, we processed and analysed the dataset using Microsoft Excel and IBM SPSS Statistics version 28.0.0 [45] for a comprehensive statistical evaluation. All responses were anonymized to protect participants' identities. The analysis primarily employed descriptive statistics, including frequencies, means, and percentages. A Chi-square test was conducted to explore whether a significant association exists between gender and adaptation strategies. The binary logistic model was used to examine how socioeconomic factors influence farmers' choice of adaptation strategies. As farmers utilized multiple adaptation strategies in combination, it was recommended to use a logistic regression approach to identify the determinants of farmers' choices regarding adaptation strategies [46]. This approach allows for the assessment of adoption choices by categorizing the dependent variables into a binary choice: either adopted or not adopted. The binary logistic model can be expressed as:

$$Y_{ij}^* = a + \sum_k \beta_k X_k + \varepsilon_{ij}, \quad (2)$$

where Y_{ij}^* is the dependent variable (hidden) for a farmer i who adopts strategy j . The X_k represents independent variables (k factors that influence the farmer's decision). The a and β_k are, respectively, the intercept and the coefficient of the model, while ε_{ij} is the error term. From Eq. (2), the condition for Y_{ij} is set to be

$$Y_{ij} = \begin{cases} 1 & \text{if } Y_{ij}^* > 0 \\ 0 & \text{otherwise,} \end{cases} \quad (3)$$

where Y_{ij} is the dependent variable (observed), indicating that the farmer i will (will not) adopt strategy j as $Y_{ij} = 1$. Therefore, the conditional probability that $Y_{ij} = 1$ is defined as:

$$\Pr(Y_{ij} = 1|x) = \Pr(Y_{ij}^* > 0|x) = \frac{\exp(\beta_k X_k)}{1 + \exp(\beta_k X_k)} = G(\beta_k X_k), \quad (4)$$

here, x denotes the particular value of the independent variable X_k for a specific observation being evaluated for its conditional probability. Where G is the binomial distribution [47].

To obtain the marginal effects that explain the significance and the magnitude of the relationship between dependent variables (i.e., adaptation strategies) and independent variables (i.e., factors influencing farmers' choices), the derivative of Eq. (4) with respect to X_k is required.

$$\frac{\partial G(\beta_k X_k)}{\partial X_k} = \Pr(Y_{ij} = 1|x) \cdot (1 - \Pr(Y_{ij} = 1|x)) \cdot \beta_k. \quad (5)$$

Then, the coefficients in Eq. (5) are explained concerning marginal effects on odds ratios [48]. Having $p_i = \Pr(Y_{ij} = 1|x)$ as the probability that a farmer i adopts the adaptation strategy j , the odds ratio is $\frac{p_i}{1-p_i}$, the ratio of the probability of adopting to the probability of not adopting [49].

$$\text{Odds} = \frac{p_i}{1 - p_i} = \frac{\frac{\exp(\beta_k X_k)}{1 + \exp(\beta_k X_k)}}{1 - \frac{\exp(\beta_k X_k)}{1 + \exp(\beta_k X_k)}} = \exp(\beta_k X_k); \ln \frac{p_i}{1 - p_i} = \beta_k X_k, \tag{6}$$

Various scholars, including Acquah-de Graft [50], Asekun-Olarinmoye et al. [51], Kabir et al. [52], Mubalama et al. [53], Mushagalusa et al. [54], and Batungwanayo et al. [46], have employed this approach to examine the factors influencing farmers’ decisions regarding adaptation measures. The model was validated using the Omnibus and Hosmer and Lemeshow tests, which assess its robustness by comparing the predictors with a model that includes only an intercept. Accordingly, it follows an asymptotic Chi-square distribution, with degrees of freedom determined by the difference between the number of variables in the predictor model and the intercept-only model [55]. The Omnibus test should yield a significant p-value (<0.05), while the Hosmer and Lemeshow test should produce an insignificant p-value (> 0.05). To evaluate the model’s accuracy, we utilize the classification method, which compares the predicted scores from the model’s independent variables against their actual responses recorded in the data. Consequently, the model’s accuracy reflects the proportion of correctly estimated positive and negative events relative to the total number of events [49]. Higher percentages indicate effective performance.

3. Results

3.1. Changes in Temperature and Rainfall Events in Eastern Province

The investigation of temperature trends has revealed a significant positive increase in annual mean temperature over Eastern Rwanda (Table 2). The mean annual maximum temperature showed no significant change. The mean seasonal minimum temperature demonstrated a notable positive change across all seasons, suggesting that the observed rise in both seasonal and annual mean temperatures is mainly attributed to increasing minimum temperatures. Rainfall amounts in the Eastern Rwanda region exhibit non-significant decreasing and increasing trends during the March to May and September to December seasons, respectively (Table 3). The onset of the rainy season has changed significantly, starting earlier than in the past. The length of the seasons indicates an increase across the region in both periods, with a significant change noted for the September to December season.

Table 2. Displays changes (in °C) with a 95% confidence interval in brackets [] for the averaged seasonal and annual means of Tx, Tn, and T in the Eastern Province of Rwanda from 1983 to 2021.

1983-2021			
Season	Tx	Tn	T
JF	0.88 [-1.02-2.74]	1.71 [0.66-2.83]	1.47 [0.28-2.62]
MAM	0.16 [-1.60-2.00]	2.37 [1.07-3.68]	1.69 [0.22-2.93]
JJA	0.85 [-0.27-1.97]	3.37 [1.75-4.81]	2.37 [0.94-3.68]
SOND	-0.37 [-2.17-1.42]	2.72 [1.10-4.46]	1.17 [-0.18-2.47]
Annual	0.30 [-1.31-1.71]	2.95 [1.64-4.45]	1.87 [0.61-3.19]

Table 3. Slope value of identified trends for rainfall events at the Eastern regional scale. The * in the results indicates that significant regional trends are observed at a 95% confidence level.

1981-2021				
Season	Rainfall amount mm/day/year	Onset days/year	Cessation days/year	Season Duration days/year
MAM	-0.01	-0.21	0.00	0.21
SOND	0.00	-0.21*	0.00	0.23*

3.2. Socioeconomic Characteristics of Respondent Farmers

Table 4 presents the socioeconomic characteristics of 204 respondent farmers (heads of household) in the Eastern Province of Rwanda. 57% of the respondents were male and 43% were female. The mean age of the respondents was 44 years old, and they had a mean farming experience of 22 years. The mean duration of working on a farm per day was 20160 s. The respondents exhibited a low level of education, with the majority (61%) having attended only primary school, and 17% reporting no formal education. The farm sizes ranged from 200 to 10000 m² for 71% of respondents, from 11000 to 20000 m² for 20%, and from 21000 m² and above for 10%, with an average size of 13000 m². Of the respondents, 48% exclusively farm on hillsides, 15% solely farm in wetlands, and 38% engage in farming activities in both hillsides and wetlands. The majority (53%) of respondents utilised inherited land for agriculture, while 17% relied on privately rented land, and 30% of respondents utilised both inherited and rented land. The primary farming objective for the majority (68%) of the respondents was to generate income while meeting home consumption needs. Meanwhile, 30% focused solely on home consumption, and 2% aimed solely at generating income. Most respondents primarily cultivated maize (90%) and beans (89%) as their main crops. While doing agriculture, 64% of respondents are also engaged in livestock breeding, while 36% do not engage in livestock activities. 37% of respondents were members of at least one farmer group, while 63% did not belong to any group. 79% of respondents reported exchanging agricultural information with fellow farmers, while 21% did not. The majority (51%) of respondents lacked access to weather information, while 49% primarily accessed it through radio broadcasts. More than half (58%) of the respondents had access to banking services and had bank accounts, while 42% were not linked to any banking institution. On average, the household size was 5 persons.

Table 4. Socioeconomic characteristics of respondents (n=204).

<i>Variables</i>	<i>Category</i>	<i>Frequency</i>	<i>Percentage (%)</i>	<i>Mean</i>
<i>Gender</i>	<i>Female</i>	88	43	
	<i>Male</i>	116	57	
<i>Age</i>	20-34	48	24	
	35-49	98	48	
	50-64	48	24	43.66
	65-80	10	5	
<i>Farming Experience (years)</i>	1-20	96	47	
	21-40	97	48	22.18
	41-60	10	5	
<i>Time in farm per day (unit is second)</i>	≤ 14400	21	10	
	18000-28800	167	82	20880
	≥ 32400	16	8	
<i>Education</i>	<i>None</i>	34	17	
	<i>Primary</i>	124	61	
	<i>Secondary_level_1_(Senior_3)</i>	22	11	
	<i>Secondary_level_2_(Senior_6)</i>	17	8	
	<i>Technical_vocation</i>	6	3	
	<i>University</i>	1	0.5	
<i>Farm size (unit is square meters)</i>	0-10000	144	71	
	11000-20000	40	20	13000
	> 20000	20	10	
<i>Farm location</i>	<i>Hillside</i>	97	48	
	<i>Wetland</i>	30	15	
	<i>Both</i>	77	38	
<i>Farm ownership status</i>	<i>Owner</i>	108	53	
	<i>Tenant</i>	34	17	
	<i>Both</i>	62	30	
<i>Farming goals</i>	<i>Home consumption</i>	62	30	

	Income	4	2.0	
	Both (Income and home consumption)	138	68	
Main crops	Maize	184	90	
	Beans	181	89	
	Cassava	63	31	
Livestock ownership	Yes	131	64	
	No	73	36	
Group membership	Yes	76	37	
	No	128	63	
Exchanging info	Yes	161	79	
	No	43	21	
Access to weather info	Yes	99	49	
	No	105	51	
Access to bank service	Yes	119	58	
	No	85	42	
Household size	1-5	136	67	
	6-10	65	32	5
	11-15	3	1.5	

3.3. Farmers' Knowledge of Weather and Climate Change

The climate variables linked to farmers' indigenous knowledge of critical agricultural indicators such as the onset and cessation of rainy seasons, are presented in Table 5. As many as 35% of respondent farmers reported that they could predict/forecast the seasonal onset based on cloud features. For example, one farmer explained: *"As the onset of rainy season approaches, we begin to observe dark clouds circulating in the sky and experience very cold mornings while the nights grow warmer,"* (farmer number 178). 19% of respondent farmers claimed to have knowledge linked to the wind direction and patterns prevalent over the region. For instance, one farmer stated: *"We recognize that the onset of the rainy season is near when, around the 5th of September, we begin to experience strong winds, which we interpret as a precursor to rainfall, and we use to say that the wind is going to fetch rain, when these winds return around the 5th to 10th of October, they bring rain,"* (farmer number 181). 13% of respondents claim to possess knowledge related to temperature patterns. For instance, one respondent mentioned: *"One of the signs of the onset of the rainy season is that we begin to experience warmer nights, accompanied by observable changes in cloud formations in the sky,"* (farmer number 84). The farmer's knowledge regarding the rainy seasonal cessation (Table 5) was mainly linked to rainfall patterns, including rainfall distribution, rainfall amount, rainfall frequency, and rainfall duration in the region. Of the respondent farmers, 46% reported that they could predict/forecast the cessation of a rainy season based on rainfall distribution. One respondent explained: *"We can tell that the rain is about to stop when we start experiencing reduced rainfall, often localized to some part of our region without extending to the whole region,"* (farmer number 116). 18% of respondent farmers claimed to have knowledge linked to the quantity of rainfall. For instance, one respondent noted: *"We know that the cessation of the rainy season is near when we start experiencing reduced rainfall, which is not equivalent to the number of clouds we observed before. Sometimes, we even observe cloud formations in the sky, but they do not result in rainfall,"* (farmer number 13). 17% of farmers surveyed asserted that they knew about the rainfall duration. For example, one farmer explained: *"We can tell that the rain is about to stop when it starts falling for a short duration and becomes localized. It may rain in one area for a brief period, then move to another part of the region in a similar manner,"* (farmer number 176). Knowledge related to rainfall frequency was reported by 11% of respondent farmers. For instance, one respondent farmer explained: *"When the seasonal rainfall is about to cease, its frequency starts to decrease. For example, it might rain on a Tuesday and then not rain again until Sunday. After Sunday, there might be another week-long gap before it rains again, continuing like this until it stops completely,"* (farmer number 43).

Table 5. Climate indicators associated with farmers’ knowledge about rainy season onset and cessation (n=204).

	Onset skills			Cessation skills	
	Frequency	Percentage		Frequency	Percentage
Cloud	72	35	Rainfall distribution	93	46
Wind	38	19	Rainfall amount	36	18
Temperature	27	13	Rainfall duration	35	17
Lightning	12	6	Rainfall frequency	22	11
Do not know	32	16	Cloud	16	8
			Temperature	13	6
			Wind	4	2
			Do not know	25	12

Figure 2 illustrates the participants’ perspectives on the causes of climate change. The majority (55%) attributed climate change to deforestation, 16% cited industrial effluents, and another 16% pointed to carbon emissions by developed countries. Additionally, 10% associated climate change with the black smoke of vehicles, while 9% linked it to the destruction of the environment. A smaller percentage (2%) attributed climate change to natural causes or ‘God’s Plan,’ and another 2% mentioned the ocean as a factor. Notably, 32% of respondents indicated uncertainty about the cause of climate change.

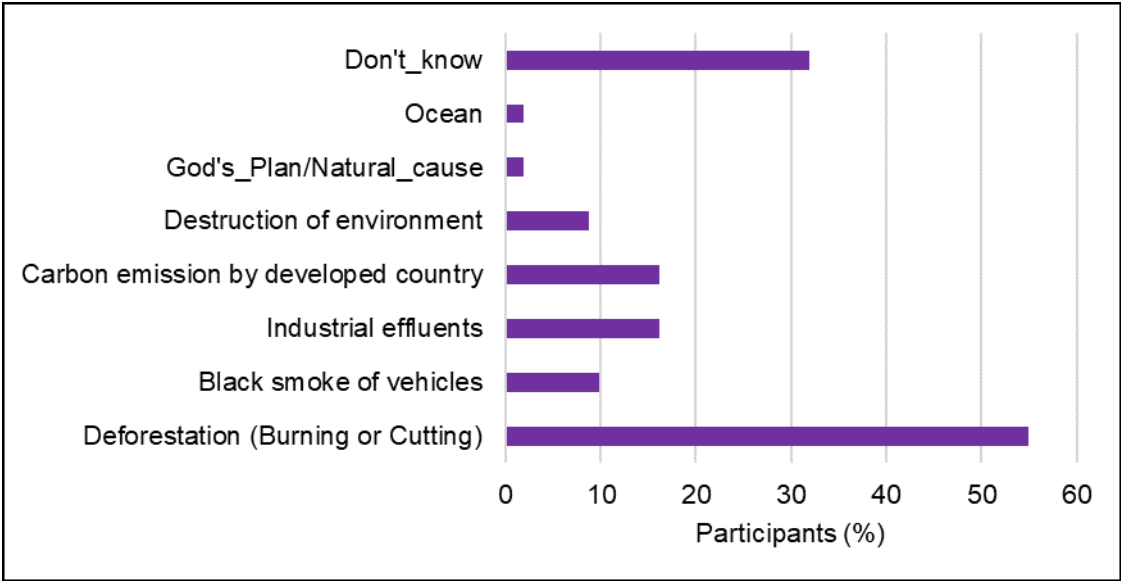


Figure 2. Farmers’ knowledge about causes or reasons for climate change (n=204).

3.4. Respondent Farmers’ Perceptions of Climate Change

The perceived changes in temperature and drought among farmers are shown in Figure 3. Of the respondent farmers, 54% reported perceiving an increase in temperature, 47% noticed an increase in the frequency of droughts, and 41% observed an increase in the duration of droughts.

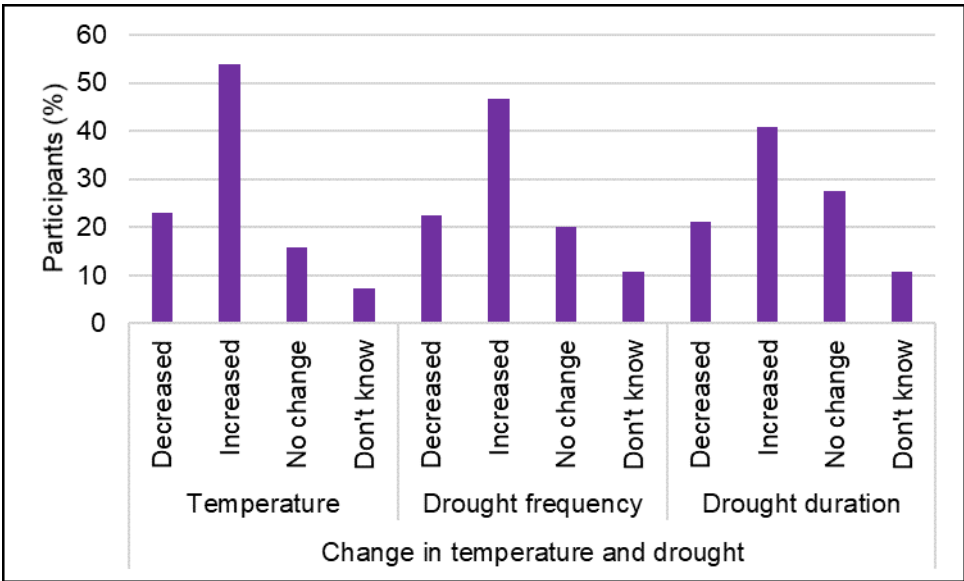


Figure 3. Respondent farmers’ perception of change in temperature and drought pattern (n=204).

Figure 4 presents the farmers’ perceptions of changes in the MAM season rainfall pattern. The majority (53%) of the respondent farmers perceived a delayed onset of the MAM rainy season and an early cessation (58%), leading to a reduction in the length of the rainy season (53%) and a decrease in the amount of seasonal rainfall (49%). Figure 5 shows the perceived changes in the SON/D season’s rainfall pattern. Similarly, to the perceived change in the MAM season, as many as 39% of respondents perceived a delayed onset of the SON/D rainy season and early cessation (39%), resulting in a reduction in the length of the rainy season (41%) and a decrease in the amount of seasonal rainfall (37%).

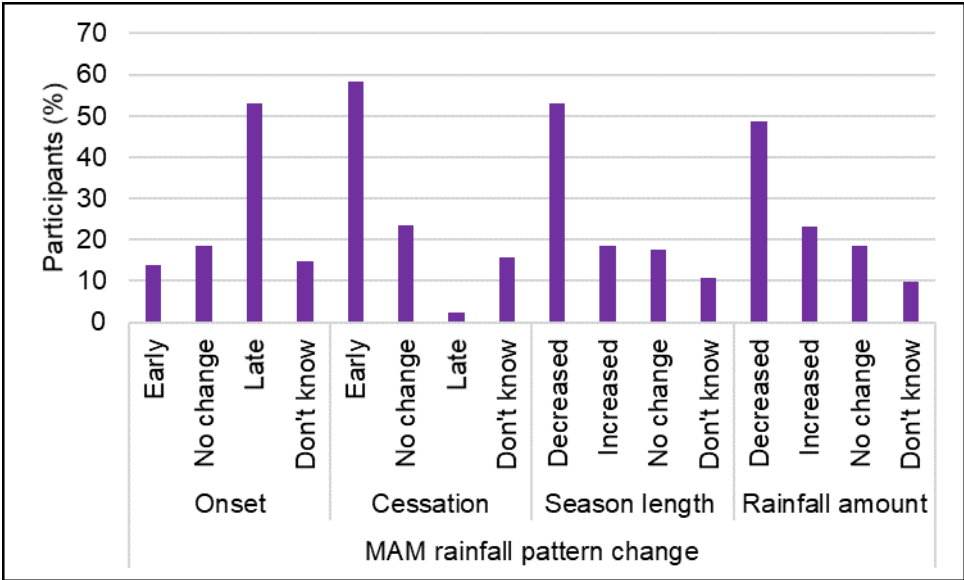


Figure 4. Respondent farmers’ perceptions of change in the MAM season rainfall pattern.

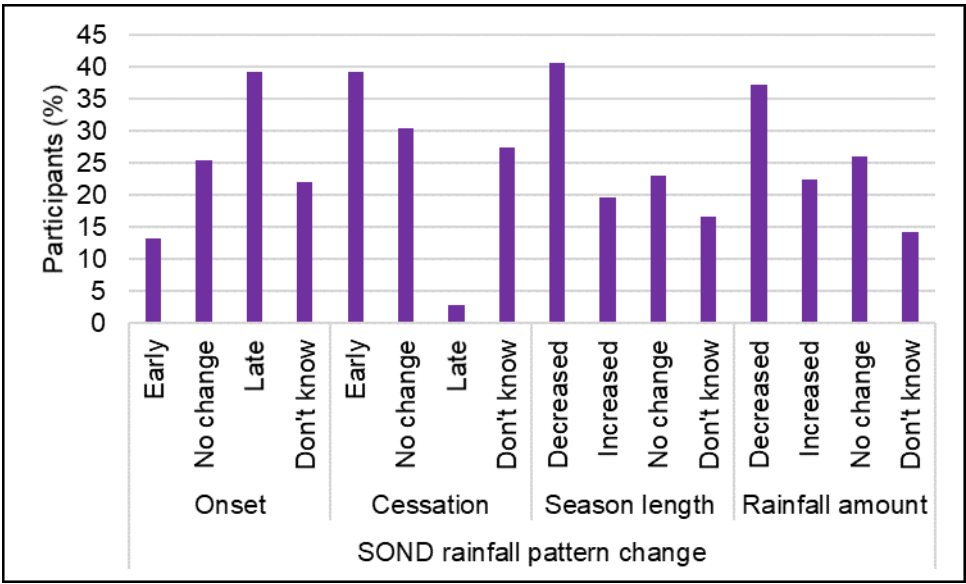


Figure 5. Respondent farmers’ perceptions of change in the SOND season rainfall pattern.

3.5. Respondent Farmers’ Perceptions of the Impacts of Climate Change

Figure 6 illustrates the perceived impacts of climate change among the respondent farmers. The majority (56%) of farmers reported crop failures caused by drought and changes in rainfall patterns. In comparison, a smaller portion mentioned soil fertility decline (1%) and the emergence of new pests (7%), resulting in reduced crop yields (20%), food shortage among families (24%), and animals (7%), income loss (6%), poverty (11%), migration (2%) and increased food costs (1%). Additionally, farmers noted that climate variations disrupted the agricultural calendar (2%).

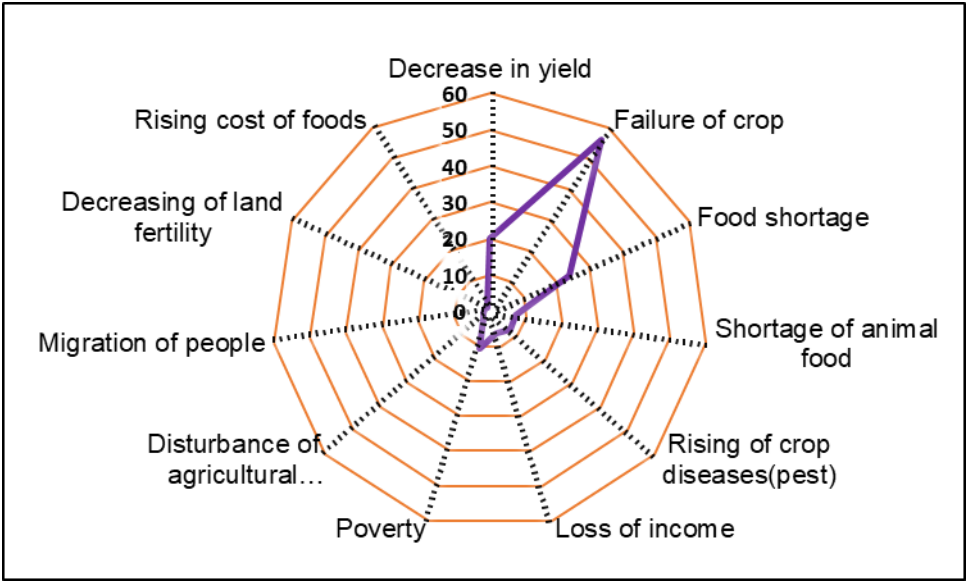


Figure 6. Percentage (%) of respondent farmers who perceived the impacts of climate change (n=204).

3.6. Climate Change Adaptation Strategies

Various adaptation strategies which were applied by the respondent farmers in response to the perceived impact of climate change are presented in Table 6. As many as 40% of respondents reported agroforestry/ planting trees, changing crop varieties (23%), application of fertilisers (23%), and changing planting dates (26%). The adoption of soil conservation (25%), use of irrigation (21%), focusing on wetlands (10%), mulching (4%), and use of pesticides (7%) were also the measures employed among the farmers.

Table 6. Climate change adaptation strategies adopted by respondent farmers (n=204).

<i>Adaptation Strategies</i>	<i>Frequency</i>	<i>Percentage</i>
<i>Agroforestry/Planting trees (PT)</i>	81	40
<i>Changing crop varieties (CCV)</i>	47	23
<i>Application of fertilizer (organic and inorganic) (AF)</i>	47	23
<i>Changing planting dates (CPD)</i>	54	26
<i>Soil conservation (SC)</i>	50	25
<i>Focus on wetland (FWL)</i>	21	10
<i>Use irrigation (UI)</i>	43	21
<i>Mulching (M)</i>	9	4
<i>Use of pesticides (UP)</i>	15	7
<i>Planting grass (PG)</i>	11	5

3.7. Barrier to the Effective Adaptation of Climate Change

Table 7 presents the farmers’ responses when they were asked about barriers hindering their adaptation to climate change. Of the farmer respondents, 28% cited insufficient financial capacity, 18% reported inadequate agricultural skills, and 21% indicated a lack of appropriate material for adaptation. Additionally, 12% mentioned the absence of timely weather information, 20% reported shortages of farm inputs when needed, and 2% noted challenges linked to the location of their farm. Moreover, 7% reported a lack of water sources near their farms, while 3% and 2% cited the high cost of agriculture inputs and materials, respectively.

Table 7. Barriers to the effective adaptation of climate change by respondent farmers (n=204).

<i>Barriers</i>	<i>Frequency</i>	<i>Percentage</i>
<i>Lack of finance</i>	58	28
<i>Inadequate info</i>	39	19
<i>Lack of material</i>	43	21
<i>Lack of weather info</i>	24	12
<i>Shortage of farm inputs</i>	40	20
<i>Lack of water</i>	14	7
<i>High cost of input</i>	7	3
<i>Land location</i>	4	2
<i>High cost of material</i>	4	2

3.8. Socioeconomic Factors Influencing Farmers’ Choice of Adaptation Strategies

Binary logistic models were used to identify the relationship between socioeconomic factors and the three most essential adaptation strategies that the farmers highlighted to be the most effective: agroforestry/planting trees (PT), changing crop varieties (CCV), and application of fertilizer (AF). The validation diagnostics of the regression logistic models is presented in Table 8. In general, with the Omnibus test of the model coefficients (test of model fit), all the models indicated good fits, confirming their ability to make predictions. It indicated chi-square values ranging between 29.940 and 45.219 and significant p-values ($\alpha = 5\%$). The results from the Hosmer and Lemeshow test (test of model fit) also confirmed how goodness-of-fit the models were, with the Chi-square values varying between 2.590 and 9.611 and no significant p-values ($\alpha = 5\%$). Furthermore, Nagelkerke’s R-squared values varying between 0.208 and 0.301 were observed. Overall, the accuracy rate of all the models was reasonable ($> 66\%$). All these confirm how models were able to determine correctly how socioeconomic factors influence the farmers’ choice of particular adaptation strategies to deal with climate change impacts.

Table 8. Analysis of the models’ significance and goodness of fit.

Omnibus Tests of Model Coefficients				
Models	Chi-square	Degree of freedom(df)	P-value	
Agroforestry/Planting trees (PT)	34.026	15	.003	
Changing crop varieties (CCV)	29.94	15	.012	
Application of fertilizer (Organic and inorganic) (AF)	45.219	15	.000	
Hosmer and Lemeshow Test				
	Chi-square	Degree of freedom(df)	P-value	
Agroforestry/Planting trees (PT)	5.316	8	.723	
Changing crop varieties (CCV)	2.59	8	.957	
Application of fertilizer (organic and inorganic) (AF)	9.611	8	.293	
Model Summary				
	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square	Model correctness (%)
Agroforestry/Planting trees (PT)	240.068	0.154	0.208	66.7
Changing crop varieties (CCV)	190.278	0.137	0.207	77.5
Application of fertilizer (Organic and inorganic) (AF)	174.999	0.199	0.301	82.4

The binary logistic regression results are presented in Table 9. The table presents the relationship between socioeconomic factors (predictors) and selected adaptation strategies using odds ratios with a 95% confidence interval (Table 9). While there were notable positive correlations among various variables examined, only those that showed statistical significance were interpreted. Gender indicated significant odds values of less than one for changing crop varieties (0.477 with a 95% confidence interval of 0.205-1.109) and applying fertilizer (0.408 with a 95% confidence interval of 0.167-1.000) adaptation strategies. This suggested that female respondent farmers were less likely to use adaptation strategies such as changing crop varieties and application of fertilizers than the male respondent farmers. Based on the Chi-square test results, we found a significant correlation between gender and the top two effective adaptation strategies: agroforestry ($\chi^2=5.264$, p-value=0.022) and changing crop varieties ($\chi^2=4.437$, p-value=0.035), while we found no significant association in the application of fertilizer ($\chi^2=3.136$, p-value=0.077). Time spent working on the farm per day showed significant odds values of less than one for the application of fertilizer’s adaptation strategy (0.751 with a 95% confidence interval of 0.553-1.020), suggesting that greater time spent on the farm by farmers significantly decreases the odds of using the application of fertilizer. Engaging in farming activities in both hillsides and wetlands indicated a positive relationship with adaptation strategies of changing crop varieties and applying fertilizer. A significant positive relationship was observed in the adaptation strategy of applying fertilizer with odds of 1.926 and a 95% confidence interval of 1.225 to 3.028. Farming to fulfill home consumption needs and generate an income from the market exhibited a positive correlation with adopting agroforestry/planting trees and changing crop varieties as adaptation strategies. Notably, farmers aiming to meet home consumption and generate a market income were significantly more motivated to adopt the agroforestry/planting trees adaptation

strategy compared to others, with observed odds of 1.668 and a 95% confidence interval of 1.099 to 2.531. Livestock ownership indicated positive correlations with all three adaptation strategies and was positively significant with agroforestry/planting trees. The odds of a farmer engaging in agroforestry/planting trees when they owned livestock were 1.979 times higher than those farmers who do not have livestock, with a 95% confidence interval of 0.965 to 4.060. Membership in farmer groups/cooperatives showed a positive correlation with all adaptation strategies, significantly influencing the changing of crop varieties and the application of fertilizer as measures for adaptation. Farmers belonging to a group or cooperative were 2.740 times more likely to change crop varieties than those not affiliated with any farmer group, with a 95% confidence interval of 1.206 to 6.226. Similarly, farmers belonging to a group or cooperative were 3.926 times more likely to apply fertilizer than those not affiliated with any farmer group, with a 95% confidence interval of 1.556 to 9.906. Exchanging information among the farmers positively correlated with adopting all three adaptation strategies. It positively influenced the adoption of changing crop varieties with odds of 3.167 and a 95% confidence interval of 0.810 to 12.375. Access to weather and forecast information showed positive correlations with all three adaptation strategies and exhibited a significant positive association with applying fertilizers. Farmers who accessed weather and forecast information were 2.271 times more likely to apply fertilizers compared to those without access to such information, with a 95% confidence interval ranging from 0.978 to 5.276. Access to bank services showed significant odds values of less than one for both changing crop varieties (0.494 with a 95% confidence interval of 0.216-1.127) and fertilizer application (0.286 with a 95% confidence interval of 0.116-0.706) adaptation strategies. These findings suggest a negative influence, indicating that farmers accessing bank services were less likely to adopt these adaptation strategies.

Table 9. Logistic regression results: odds ratios and 95 % confidence interval showing socioeconomic factors influencing farmers’ choice of selected adaptation strategies. .

<i>Variables</i>	<i>PT</i>	<i>CCV</i>	<i>AF</i>
<i>Gender</i>	0.700 [0.345-1.418]	0.477* [0.205-1.109]	0.408** [0.167-1.000]
<i>Age</i>	0.965 [0.915-1.017]	0.963 [0.904-1.026]	1.009 [0.951-1.070]
<i>Education level</i>	1.037 [0.717-1.502]	0.963 [0.629-1.474]	1.013 [0.635-1.616]
<i>Farmer experience(years)</i>	1.019 [0.969-1.072]	1.036 [0.977-1.099]	1.002 [0.946-1.061]
<i>Time spent/day (Hours)</i>	1.007 [0.810-1.252]	0.843 [0.647-1.099]	0.751* [0.553-1.020]
<i>Farm size (hectares)</i>	0.885 [0.690-1.134]	1.013 [0.780-1.314]	0.773 [0.498-1.201]
<i>Farm location</i>	0.739 [0.513-1.064]	1.052 [0.697-1.587]	1.926** [1.225-3.028]
<i>Land-holding status</i>	1.158 [0.803-1.670]	1.324 [0.867-2.022]	1.008 [0.638-1.591]
<i>Farming goal</i>	1.668** [1.099-2.531]	1.245 [0.745-2.083]	0.770 [0.460-1.288]
<i>Livestock ownership</i>	1.979* [0.965-4.060]	1.250 [0.530-2.948]	1.674 [0.679-4.128]
<i>Farmer group membership</i>	1.587 [0.776-3.245]	2.740** [1.206-6.226]	3.926** [1.556-9.906]
<i>Exchanging info</i>	2.024 [0.770-5.320]	3.167* [0.810-12.375]	1.118 [0.321-3.895]
<i>Access to weather info (Radio)</i>	1.234 [0.639-2.384]	1.272 [0.592-2.732]	2.271* [0.978-5.276]
<i>Access to bank services</i>	0.703 [0.344-1.437]	0.494* [0.216-1.127]	0.286** [0.116-0.706]
<i>Household size (Individuals)</i>	1.043 [0.893-1.218]	1.009 [0.846-1.205]	0.994 [0.818-1.208]
<i>Constant</i>	0.261	0.203	0.403

* and ** show significant levels at 0.1 and 0.05, respectively.

4. Discussion

The respondent farmers’ socioeconomic characteristics show that males and females were almost equally represented in this study, and the farming experience was, on average, above 22 years.

This indicates that males and females were exposed to the same negative impacts of changes in climate conditions over Eastern Rwanda in the last 20 years. Most respondent farmers combined agriculture and livestock rearing and exercised them on a small plot of land (average $\leq 13000 \text{ m}^2$). This agrees with NISR [28], which reported that 64.2% of Rwandan households are engaged in crop farming and animal breeding. The respondent farmers were mainly involved in the agriculture of staple food crops, including maize, beans, and cassava. Low education levels among the respondents were observed as the majority reported having attended only primary schools, and others reported having no formal education. This aligns with the NISR [28] report indicating that the majority (53.9%) of the Rwandan population attended only primary school, while no education level stands at 22.3%. This significantly affects adaptation strategies that require a certain level of understanding [56].

Regarding indigenous knowledge, the respondent farmers indicated they have indigenous knowledge and local experience in predicting local weather conditions. The knowledge of rainy seasonal onset was primarily associated with observing dark clouds in the sky, wind direction and intensity, exceptionally high night-time temperatures, and lightning and thunder occurring at night without rainfall. Conversely, the indigenous knowledge of rainy seasonal cessation was mainly linked to observing localized rainfall in the region and decreased rainfall amounts, frequency, and duration. Some farmers mentioned the observation of a transparent cloud in the sky, temperature increase, and wind intensity. This agrees with many scholars [57,58] who have identified that in many East African countries, farmers still use indigenous knowledge to make critical decisions for agricultural practices. However, the accuracy of indigenous knowledge in predicting weather remains uncertain. Therefore, the integration of traditional and scientific knowledge could enhance farmers' capacity to develop strategies for coping with environmental changes [59–62].

Farmers indeed perceived the causes or reasons for climate change. Deforestation was the most reported cause, followed by industrial effluents and carbon emissions from developed countries. The black smoke of vehicles, destruction of the environment, natural causes, and the ocean were also mentioned as causes of climate change. This indicates that farmers knew the importance of limiting deforestation and protecting the environment to mitigate climate change. These findings align with similar studies conducted in Bangladesh [52] and Nigeria [51], stating that even at a small-scale level, farmers still have some knowledge about the cause of climate change.

As many as 85% of the respondent farmers agreed that the climate has changed. However, they varied in their ability to articulate the reasons behind the observed changes in the climate system. Many participants reported increased temperature, drought frequency, and drought duration among the perceived changes. On the other hand, for the rainy seasonal level, most farmers perceived a decrease in seasonal rainfall amounts and the number of rainy days. At the same time, late-onset and early cessation for both the MAM and SON seasons were also perceived. These perceptions are in line with several studies conducted on Rwanda [13–15,17], indicating an increase in temperature and decrease in rainfall over many parts of Rwanda in the past recent decades. Particularly in the Eastern Province, a study by Sebaziga et al. [11] noted a decrease in seasonal rainfall in many parts. The perceived decline in seasonal rainfall also aligns with a study by Rwema et al. [16]. This study noted a decrease in seasonal rainfall at many stations in the Eastern Province, where a notable change in MAM rainfall amounts was recorded, mainly in the Southern part. Additionally, studies on temperature have recorded a highly increasing trend over the Eastern Province [17]. A study by Butera et al. [63] with rice farmers in the Eastern Province also agreed with our findings, where the majority of farmers perceived an increase in temperature. It was noted that temperature increase and rainfall decrease contributed to the recurring severe and prolonged drought events in recent decades over Eastern Rwanda [20,21,64]. Acknowledging climate change implies the farmers' willingness to take several measures to adapt to the perceived change. However, a small number of the farmers believed that there was no change, and this category of farmers needed particular attention to enhance their understanding of climate change, mitigation, and adaptation.

Since we interviewed farmers from the Eastern Province, the area highlighted to be the most prone to climate change impact, such as drought [21], all the participants were able to report one or

two negative impacts of climate change they faced in their farming experience. The most observed impacts were crop failures, reduced yield, and food shortage. Farmers also reported the rise of crop diseases (pests), decreased land fertility, and disturbed farming calendars. These impacts were expected for the farmers whose farming heavily relied on seasonal rainfall [65]. The farmers' perception of these impacts is supported by several studies reporting the negative impact of increasing temperatures and changing rainfall patterns at local and regional scales [46,54,66,67]. As climate change remains the major challenge of the century, small-scale farmers need to adjust their agricultural practices to cope with changing climate conditions by devising strategies that ensure their livelihoods are sustained [54,68].

Acknowledging climate change and its impacts, only 5% of respondent farmers believed they bear responsibility for adaptation, and 19% assigned this responsibility to the government. In comparison, the majority (75%) perceived a shared responsibility between both parties in developing sustainable adaptation measures. This was mentioned because some adaptation technology requires high investment, which cannot be easily affordable for smallholder farmers (e.g., irrigation technology). However, in the Eastern Province, the respondent farmers were applying several adaptation strategies to deal with the perceived impact of climate change. Those strategies include agroforestry/planting trees, changing crop varieties, application of fertilizer (organic and inorganic), changing planting dates, soil conservation, focusing mainly on the farms near water sources, use of irrigation, mulching, and use of pesticides. The respondent farmers reported that agroforestry/planting trees, changing crop varieties (CCV), and applying fertilizer (AF) were the most effective adaptation strategies. Undoubtedly, the last two (CCV and AF) were expected to be mentioned as it has a major influence on increasing growth and production of maize and bean crops [53,69,70] which are mainly grown in the Eastern Province. According to a study by Murthy et al. [71], agroforestry is the most sustainable strategy, offering substantial impacts on soil preservation, biodiversity conservation, and numerous socioeconomic advantages.

Similarly, in other areas where changes in climate conditions were reported to threaten agriculture, smallholder farmers attempted several strategies at the same time to cope with the impact of climate change [46,54,72]. It is recommended to use different adaptation strategies in combination to improve their effectiveness [73].

The main barriers that hindered farmers from adapting to climate change in the study area included limited financial capacity, lack of information (both on the climate and agriculture), and lack of technology and farm inputs. It was also mentioned that the high cost of inputs and technology required for adaptation challenged farmers in the study area. This is in line with the study by Butera et al. [63] at the Eastern Province level and by the World Bank [74] at Rwanda's country level. These reported barriers are commonly encountered by smallholder farmers in Sub-Saharan Africa, as highlighted in several studies [53,72,75–77]. Rwanda's government shows the political will to support farmers in overcoming these challenges and increasing agricultural resilience to climate change. This is confirmed by the existing several initiatives such as "NKUNGANIRE" and "Hinga Urishingiwe," mainly for the farmers who are growing tea, coffee, Irish potato, maize, rice, cassava, soybeans, and beans [56,74,78]. NKUNGANIRE is a national farmers' subsidy program that aims at helping the poor and the general population get necessary inputs while enhancing the coordination of supply and demand within the supply chain [56]. Hinga Urishingiwe is an insurance-based program aimed at covering damages as a result of extreme weather conditions, such as temperature fluctuations, sunlight exposure, wind intensity, or rainfall patterns, which may lead to crop yield losses throughout the entire duration of the crop growth until physiological maturity [74]. Farmers must embrace these programs to benefit from the available interventions tailored to help them sustainably increase their resilience.

About the factors that influenced farmers' choice of adaptation strategies, we found that having the goal of meeting family needs and generating a market income positively and significantly influenced agroforestry/planting trees as an adaptation strategy. This agrees with studies indicating different socioeconomic benefits of agroforestry at farm and household levels [71]. Livestock

ownership positively influenced farmers' choices to implement all three adaptation strategies, particularly agroforestry, which showed a significant correlation. Besides providing manure for crop fertilization, livestock is a source of income through milk and meat production. Thus, this enhances farmers' financial resources and enables them to try various adaptation measures regardless of the associated costs [79]. Farmer group membership and exchanging information were also discovered to positively influence farmers to implement all three adaptation strategies, particularly changing crop variety and applying fertilizers, which showed a significant correlation. This is because group meetings provide farmers with opportunities to exchange information and share their experiences, enabling them to advise each other on the most effective adaptation measures implemented on their farms [80–83]. Moreover, access to climate and weather information positively influenced the adoption of all three adaptation strategies, significantly applying fertilizers. This aligns with findings from various scholars [46,84], who have highlighted the significant positive impact of access to climate and weather information on farmers' adaptation decisions. It is crucial to pay attention to the type and quality of information provided to farmers to prevent any misinformation, as the information they receive directly influences their decision-making process.

This study analyses farmers' indigenous knowledge, perceptions of climate change impacts, adaptation strategies, barriers to adaptation, and socioeconomic factors influencing adaptation in Rwanda's Eastern Province. Further research should validate indigenous knowledge for seasonal prediction and explore its fusion with scientific methods for improved forecasting accuracy. Studies are needed to quantify losses from perceived impacts and assess adaptation strategy effectiveness. Exploring indigenous knowledge integration into farmers' decisions and considering all the available adaptation strategies in relation to socioeconomic factors should be prioritized in future studies.

5. Conclusions

The present study examined farmers' indigenous knowledge, perceptions of changes in the climate system, impacts of perceived changes, adaptation strategies employed by farmers, barriers constraining these adaptation strategies, and the socioeconomic determinants of adaptations to climate change in the Eastern Province of Rwanda. Data collected at the household level from interviews with farmers in five districts of Eastern Rwanda were analysed, along with meteorological data from 1981 to 2021.

It was observed that farmers have indigenous knowledge regarding meteorological indicators, which they use for predicting/forecasting important agricultural events such as rainy seasonal onset and cessation. Most farmers were aware of climate change and perceived an increase in temperature and a decrease in seasonal rainfall, which corresponded to the observed change in meteorological data. Farmers reported that the most significant cause of climate change is deforestation. Respondent farmers indicated that most of the observed impacts were crop failures, reduced yield, and food shortage.

Farmers were adopting various adaptation strategies such as agroforestry/planting trees, changing crop varieties and planting dates, application of fertilizers, soil conservation, and use of irrigation. Among these strategies, the most valuable strategies identified by farmers were agroforestry, changing crop varieties, and application of fertilizers, and their adoption was highly influenced by socioeconomic factors, including livestock ownership, farmer group membership, exchanging information, and access to weather and climate information, among others. Findings also showed that the significant barriers that hindered farmers from adapting to climate change included limited financial capacity, lack of information (both climate and agriculture), and lack of technology and farm inputs when needed.

Recommendations drawn from this study include:

1. Climate research highlights significant shifts in temperature and rainfall patterns across the Eastern Province. While many farmers accurately recognize these changes in alignment with scientific findings, a considerable portion remains unaware or misinformed. This lack of awareness can impede the successful adoption of adaptation strategies, as understanding the nature of climate change and

its implications is critical for fostering resilience. To address this challenge, it is essential for stakeholders, including government authorities, farmers, and community organizations, to take concerted action to mitigate the impacts of climate change in Eastern Rwanda. Priority should be given to capacity-building programs that educate farmers on the observed climatic shifts, their consequences, and the importance of adopting effective adaptation, mitigation, and prevention strategies. Enhancing farmers' knowledge and awareness will contribute to building resilience and promoting sustainable agricultural practices in the region.

2. We recommend that stakeholders establish a participatory framework that actively involves farmers in decision-making processes. This study reveals that farmers not only recognize climate change but also possess a deep understanding of their local climate conditions, which is vital for strengthening their resilience. Their localized knowledge is an invaluable resource that must be integrated into adaptation planning. Excluding farmers from these discussions could lead to the development of strategies that fail to address their most critical needs, thereby undermining the effectiveness and sustainability of adaptation efforts.
3. The study highlights that farmers encounter numerous challenges, particularly those linked to financial constraints. To address this, stakeholders must strengthen their collaboration with farmers to gain a deeper understanding of these difficulties. This approach will enable the development of support programs and solutions that are both cost-effective and aligned with farmers' financial realities. Efforts to improve the financial capacity of farmers are especially crucial for fostering resilience and sustainable agricultural practices in Eastern Rwanda.
4. Since adaptation methods like agroforestry have been widely embraced by farmers, it is vital for the government and other stakeholders to prioritize selecting tree species that are best suited to the soil and climatic conditions of Eastern Rwanda. Adopting this targeted approach can maximize the benefits of agroforestry, strengthening farmers' resilience by improving health, nutrition, and financial stability, all of which are influenced by the choice of tree species planted.

Beyond the scope of this study, further research endeavors could focus on validating indigenous knowledge for seasonal prediction and investigating its integration with scientific methodologies to bolster forecasting precision. Additionally, there is a need for studies to quantify the losses incurred due to perceived impacts and evaluate the efficacy of implemented adaptation strategies. Exploring the incorporation of indigenous knowledge into farmers' decision-making processes within the study area would also yield valuable insights. Given that the examination of the relationship between socioeconomic factors and adaptation strategies did not encompass all available options, future studies may seek to expand upon this investigation by exhaustively documenting the full spectrum of adaptation strategies as reported by farmers.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Climate datasets were provided by the Rwanda Meteorology Agency (Meteo Rwanda). The data can be accessed through the online portal at <https://www.meteorwanda.gov.rw>. The field survey data that support the findings of this study are available from the corresponding author upon reasonable request.

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