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Climate Change Adaptation Strategies and Determinants of Adoption Amongst Smallholder Farmers in Jemma Sub-basin, Central Ethiopia

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Abstract Climate change is causing significant suffering for rural farmers in Ethiopia, especially those in the Jemma sub-basin, whose livelihoods rely on rain-fed agriculture. The primary aim of this study is to identify key adaptation options and the factors that influence smallholder farmers' decisions to adopt these strategies in response to climate change and variability in the Jemma Sub-Basin. A total of 366 households were randomly selected using a probability proportional to size sampling technique from highland, midland, and lowland kebeles. Semi-structured questionnaires were utilized to gather both quantitative and qualitative data through household surveys, focus group discussions, and key informant interviews. Hence, descriptive statistics and the multinominal logit model were employed to analyze the demographic characteristics and factors influencing farmers' adaptation choices. The findings revealed that adjusting planting dates, improved seeds, soil and water conservation, irrigation, livelihood strategies, and crop diversification are the most prevalent adaptation options practiced by smallholder farmers in the study area. Adjusting planting dates and soil and water conservation are positively and significantly correlated with lowland agroecology and access to information. Additionally, livelihood strategies and crop diversification are positively affected by socioeconomic factors such as gender, family size, total annual income, access to credit, and access to information. The results further indicated that the adoption of irrigation is significantly and positively influenced by gender, age, access to credit, access to information, and market access. In contrast, improved seeds, soil, and water conservation, as well as diversification of livelihoods, showed negative and significant correlations with age and landholdings. Ultimately, the results suggest that effective policies should promote the establishment of efficient microfinance institutions, enhance farmer awareness, and improve infrastructure. Furthermore, the findings advocate for the promotion

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and expansion of agroecological and gender-based research to achieve a more comprehensive understanding of farmers' adaptation options.

Keywords: agroecology, comparative analysis, non-adopters, multinominal logit model, Upper Blue Nile

1. INTRODUCTION

Climate change is among the most challenging and complex problems facing global agricultural development, due to its multifaceted impacts on food security, livelihoods, and ecological sustainability (IPCC, 2014; Tesfahunegn et al., 2016). Several studies highlight that rural communities in low-income countries are particularly vulnerable to climate change, primarily because their livelihoods rely heavily on climate-sensitive natural resources (Das et al., 2020; Ureta et al., 2020). Agriculture is the most important economic sector in Africa; however, the sector is more vulnerable to climate change than any other socioeconomic activity (Elum et al., 2017; IPCC, 2022). Furthermore, future predictions show, agricultural production will decline by 15.9% globally, 19.7% in developing countries, and a staggering rate of about 15–35% in Africa by the 2080s (Becker & Elliot, 2021). This is due to the continent's dependence on rain-fed agriculture and low adaptive capacity (Bouteska et al., 2024).

According to World Bank, (2020) report, agriculture is a source of livelihood for more than 80% of the Ethiopian population. It also contributes up to 37.5% of the country's domestic product (Leogrande, 2023). Despite its contribution to the overall economy, the sector is predominantly rain-fed and is therefore vulnerable to climate change and extreme events (Dendir & Simane, 2019). These extreme vulnerabilities to climate change and variability in Ethiopia is because of very high dependence on rain-fed agriculture which is sensitive to climate variability and change; underdevelopment of water resources; low health service coverage; high population growth rate; low economic development; low adaptive capacity; weak institutions and lack of awareness to climate change and variability (World Bank, 2021).

Adaptation to climate change impacts in general and the agriculture sector in particular is an existing phenomenon (NMA, 2007; Gezie, 2019). However, farmers living in different agroecologies are likely to implement different adaptation options to climate change pressures (Kassie et al., 2015; Atinkut & Mebrat, 2016). For instance, farmers in highland agroecological zones implement agroforestry, soil and water conservation, and crop diversification as prevalent adaptation strategies (Simotwo et al., 2018; Asfaw et al., 2019; Teshome et al., 2021; Chemeda et al., 2023). Whereas, midland areas widely practice off-farm activities such as daily wage labor and firewood sales (Abuhay & Hailu, 2024) and adjusting planting dates is commonly practiced in lowland agroecology’s (Jamshidi et al., 2019; Ponce, 2020; Aboye et al., 2023). Improved livestock breeds (Faisal et al., 2021), destocking (Sintayehu et al., 2025), herd mobility (Ayal & Radeny, 2017), and shifting from cattle to goats and sheep (Ewalo & Vedeld, 2023). However, several socioeconomic and biophysical characteristics, such as gender, age, education, agroecology, livestock production, off-farm income, access to credit, and extension services, might affect farmers' options for adaptation (Berman et al., 2015; Opiyo et al., 2016).

The study area, Jemma sub-basin, is one of Ethiopia's leading sorghum suppliers (Temeche et al., 2021), and among the eight good-performing areas in crop production (Mare et al., 2024). However, the sub-basin is characterized by severe soil erosion and is the most vulnerable area to frequent droughts and cold temperatures in the Blue Nile basin (Betrie et al., 2011; Tesso et al., 2012). Smallholder farmers in the Jemma sub-basin facing climate change hazards and weather-related impacts. Over the past three decades, climate variability has been an issue with an increase in precipitation and temperature extremes (Worku et al., 2018), which has a significant negative impact on crop production (Alemayehu & Bewket, 2016; Gonfa et al., 2022). As a result, it is crucial to investigate adaptation measures and determinants to reduce the anticipated adverse impacts of climate variation to help smallholder farmers lessen the existing outcome of a fluctuating environment (Amare & Simane, 2017a; Raza et al., 2019).

Various studies have been conducted to examine and identify the impact and adaptation strategies of climate change in different parts of Ethiopia (Zeray & Demie, 2015; Belay et al., 2017; Esayas et al., 2019; Asrat & Babiso, 2020). However, the effectiveness of adaptation and mitigation measures at the community and individual levels requires further study (Attems, 2019). Furthermore, studies in Ethiopia demonstrate that adaptation strategies vary significantly across different regions, influenced by local agroecological zones, socioeconomic and environmental conditions (Berman et al., 2015; Opiyo et al., 2016; Amare & Simane, 2017b). Nevertheless, information on the acceptance and determinants of farmers' adaptation strategies from an agroecological perspective remains a critical gap. This limitation restricts the ability to optimize agricultural productivity, ensure sustainable crop production, and build robust household resilience to face a rapidly changing climate (Maguza-tembo et al., 2017).

Therefore, site-specific studies are essential as farmers' adaptation measures vary spatially. Hence, this research investigated smallholder farmers’ adaptation strategies and determinants of adaptation mechanisms to the impact of climate change in different agroecologies of the Jemma sub-basin. The specific objectives of this study were (i) to identify and compare climate change adaptation strategies across different agroecological zones in the Jemma sub-basin, (ii) to analyze the key determinants influencing farmers' choice of adaptation strategies. We expected that climate change adaptation strategies would vary across agroecological zones in the Jemma sub-basin as influenced by farmers' adaptation choices and institutional support. Also, we assumed that the challenges and barriers to climate adaptation are not uniform across the agroecological zones of the study areas.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

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The Jemma sub-basin, located in the Central Highlands of Ethiopia, is one of the highest sub-basins of the Upper Blue Nile River basin. The sub-basin is located at 9º0'0" - 11º 0'0" Northern latitude and 38º30' 0" to 4º0'0" Eastern longitude, and the total area of the sub-basin is approximately 15,803 km^2 (Figure 1). The sub-basin spans across the Amhara and Oromia regional states. As per the 2007 Ethiopian census, the population residing in the Jemma Sub-Basin was 1,605,876, with a growth rate of 1.7 and an average population density of 106 persons/km^2 (CSA, 2007). Assuming geometric population growth, the projected population of the Jemma sub-basin in 2025 is approximately 2,175,150, making the population density 144 persons/km^2. Crop cultivation and livestock rearing are the primary means of livelihood of the residents. Major crops cultivated in the sub-basins are wheat, barley, teff, maize, and sorghum. The sub-basin is characterized by uneven topography and dissected terrain where elevation varies over short distances and exhibits diverse agroecology ranging from cold, humid sub-Afroalpine to warm, sub-humid lowland areas. The Jemma sub-basin receives annual rainfall ranging from 697 to 1475 mm. The mean yearly temperature of the sub-basin is between 9 and 24°C, and the elevation ranges from 1040 m to 3814 m above sea level. Based on the FAOs soil classification, the Jemma sub basin features a diverse range of soil types, including Eutric Vertisols (28.07%), Lithic Leptosols (37.44%), Chromic Lixisols (8.07%), Pelvic Vertisols (6.82), Haplic Luvisols (5.79%), Haplic Acrisols (6.82%). Eutric Fluvisols, Umbria Nitisols, and Alic Nitisols cover a small part of the lower basin. Notably, Leptosols and Vertisols are the main soil types covering more than 70% of the Jemma sub-basin. Sandy and clay loam are the major soil texture classes in the sub-basin (Ali et al., 2015; Worku et al., 2021). The land use/land cover types in the Jemma sub-basin include cropland (55.2%), grazing land (29.9%), bare land (1.4%), built up (3%), and forest land (10.2%). and water bodies (0.3%).

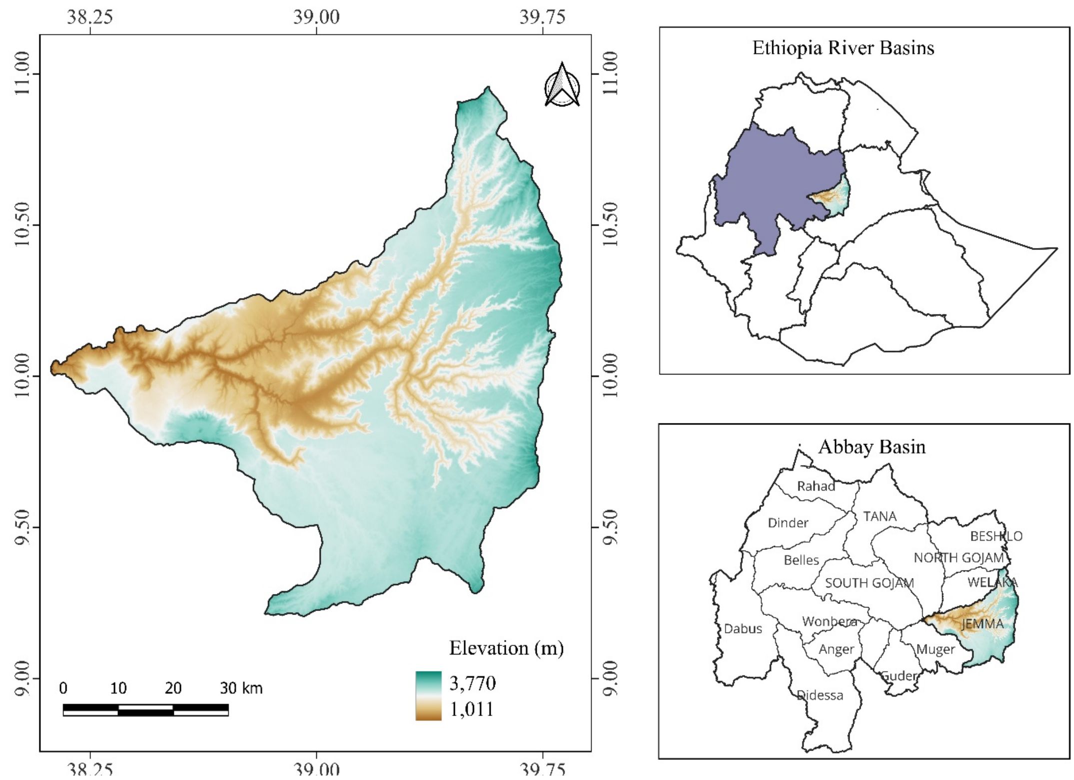

Figure 1. Map of the study area

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2.2 Sample Size and Procedures

Both probability and nonprobability sampling techniques were applied to select the required sample households in the study area. The research employs a multistage sampling technique to determine the study area, agroecological zones (AEZs) within the sub-basin, and woredas[4] and Kebeles within the selected agroecological zone, and individuals from each Kebele[5] for the data collection in various stages. First, we select Menz Mama, Siyadebirna Wayu, and Merhabete woredas purposively from highland, midland, and lowland agroecology based on their dominant agroecological zones, demographics, and livelihood conditions (Table 1). Secondly, Kebeles were clustered into their respective agroecological zones, and then three highland, two midland, and three lowland kebeles were randomly selected (Table 1). Finally, 366 sample households were randomly selected using a probability proportional to size (PPS) sampling technique guided by Kothari's (2004) sample size determination formula.

$$n = \frac{Z^2 * N * p * q}{e^2(N-1) + Z^2 * p * q} \tag{1}$$

Where n = desired sample size; N= total number of households in three kebeles, z = value of standard variation (1.96), e= acceptable error (0.05), N=total number of households in the selected AEZs=7937, p= the proportion of the target population estimated to have characteristics being measured (50% is taken or 0.5), and q= 1-p. Then, p = 0.5, q = 0.5, considering a 95% confidence level, the related standard normal deviation is z = 1.96, and the desired accuracy is at a 0.05 level.

$$n = \frac{1.96^2 * 7937 * 0.5 * 0.5}{0.05^2(7937-1) + 1.96^2 * 0.5 * 0.5} = 366 \tag{2}$$

Table 1. Sample households in each selected agroecological zone of the Jemma sub-basin

Agroecology	Woredas	Sample Kebeles	Household Heads	Sample households
Highland	Menze Mama	04	1053	49
		08	856	39
		010	721	33
Midland	Siyadebirna Wayu	Senketa	778	36
		Motelemi	767	35
Lowland	Merhabete	Buyu	1350	62
		Geren	1162	54
		Arogenda	1250	58
Total		8	7937	366

Additionally, a purposive sampling approach was employed to select the Focus Group Discussants (FGDs) and Key Informants (KIs). The respondents were intentionally chosen based on their social standing and extensive knowledge of the environmental, social, and

[4] *Woreda* refers to the fourth tier of government administration unit, which is closely equal to district.

[5] *Kebele* refers to the fifth tier of government administration unit.

economic conditions of the study areas, both past and present. Participants came from various social groups, including women, men, youth, elders, religious leaders, and kebele officials.

2.3 Data Sources and Collection Methods

Both qualitative and quantitative data were collected from primary and secondary data sources. Primary data were collected from various individuals using household survey questionnaires, interviews with key informants, focus group discussions, and field observations. The questionnaire survey was used to collect information on households' perception of climate change, patterns of temperature and rainfall, climate extremes, impacts of climate change, prevailing uncertainty, and adaptation strategies. Moreover, in each kebele, one focus group discussion, consisting of 8 members, was held, and a key-informant interview was conducted with 15 community representatives. Secondary data is considered for the data triangulation by reviewing various documents from different sources, such as CSA, NMA, and research reports of relevant organizations operating in the study area.

2.4 Data Analysis

After completing the household survey, the data were numerically coded and entered into SPSS 20. Descriptive statistics, including frequency, mean, maximum, minimum, and standard deviation, as well as inferential tests such as the Chi-square test, were used for the analysis. Qualitative categorical data were examined using frequency counts and the Chi-square test, while continuous quantitative variables were analyzed using one-way ANOVA. After computing descriptive statistics and inferential analysis, a multinominal logistic regression model was employed to identify the key determinants influencing households' adoption of various adaptation options. The dependent variable in this model was categorical, with multi-outcome, reflecting the diverse range of adaptation options considered. STATA 18 and the Statistical Package for Social Sciences (SPSS) version 20 were utilized to analyze the data. The MNL model was applied to model decisions across more than two categories.

2.5 Model Description

To explain the MNL model, let y represent the random variable that can take the values {0, 1, J} where J is a positive integer, and x denotes a set of conditioning variables. In this case, y refers to household adaptation measures, while x comprises the explanatory variables hypothesized to influence the choice of the available adaptation options. The MNL model was employed to show how certain changes in the elements of x influence the response probabilities, P (y = j|x), j = 0, 1, J. P (y = j|x) is known after determining the probabilities for j = 0,1, 2, J, which must sum to unity P (y = j/x) will be determined once the probabilities for j = 2…J are known.

$$P = \left(y = \frac{1}{x} \right) = 1 - \left(P2 + P3 + ...Pj \right) \tag{3}$$

In the MNL model, it is usual to designate one as the reference category. For a dependent variable with *j* categories, this requires calculating j−1 equations, one for each category relative to the reference category, to describe the relationship between the dependent and independent variables. The reference categories were chosen arbitrarily, based on theoretical motivation. The estimation of the MNL model for this study was conducted by normalizing one category named "base category" or "reference category". The theoretical explanation of the model is that in all cases, the estimated coefficient should be compared with the base group or reference category (Gujarati & Porter, 2009). The choice of the reference category is based on empirical literature and is theoretically motivated. The generalized form of probabilities for an outcome variable with *j* categories is:

$$\Pr = \left(yi = j \middle| x \right) = prij = \frac{\exp\left(x' \beta j \right)}{1 + \sum_{j=2}^{j} \exp\left(x' \beta j \right)}, \text{ j=1, 2, … j} \tag{4}$$

where P stands for probability, j stands for adaptation options, and *x* stands for explanatory variables, and *b*j = k _ 1 is the coefficient, j = 1, 2,..., M.

The multinominal logistic regression model equation requires the independent irrelevant alternative assumption (IIA). This assumption states that the probability of selecting a particular adaptation option must be independent of the probability of choosing another adaptation option. In other words, the ratio of the probabilities (Pj/Pk) for any two options should remain unaffected by other options. The parameter estimates of the MNL model indicate only the direction of the effect of the independent variables on the dependent variable, but they do not convey the actual magnitude of change or probabilities. Therefore, the marginal effects or marginal probabilities are functions of the probability itself and are used to measure the expected change in the probability of a specific choice in response to a unit change in an independent variable from the mean and computed as:

$$\frac{\partial pi}{\partial xk} = pj \left(\beta jk - \sum_{j=1}^{j=1} pj \beta jk \right) \tag{5}$$

2.5.1 Multicollinearity and Autocorrelation Test

Before computing the final regression model, all the proposed explanatory variables listed in Table 3 were checked for statistical issues such as multicollinearity. Multicollinearity may occur when there is a linear relationship among explanatory variables, leading to potential complications such as incorrect signs for the estimated regression coefficients, lower t-ratios for many regression variables, and inflated R-squared values. To detect multicollinearity problems between the model explanatory variables, the variance inflation factor (VIF) was employed in this study.

$$VIF = \frac{1}{1 - R_j^2} \tag{6}$$

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Where VIF refers to the variance inflation factor, R_j^2 is the corrected square of the multiple correlation coefficients that emerge from regressing one explanatory variable (j) against all others. Multicollinearity amongst explanatory variables can be reported if a VIF of 5 or 10 is detected (O'Brien, 2007). Additionally, the Durbin−Watson test (d) was employed to evaluate the autocorrelation. As *d* is approximately equal to 2(1-r), where r is the sample autocorrelation of the residuals, d=2 indicates no autocorrelation (Durbin & Watson, 1971). The model diagnosis result shows that the likelihood ratio statistic (LR chi-square 594.37) was found to be highly significant (P<0.0000). Subsequently, the model was assessed for the validity of the independence of irrelevant alternatives based on the principles of the Hausman specification test. The results showed no multicollinearity problem as the mean VIF was 2.204 (Table 2). In addition, the result of the Durbin-Watson test (d) was 1.973, meaning no autocorrelation between the explanatory variables. Therefore, the logistic model was deemed adequate to explain the dependent variable.

Table 2. Model diagnosis test

Variable	VIF	1/VIF	Variable	VIF	1/VIF
Agroecology	2.322	0.430632267	Landholding size in ha	1.943	0.514555227
Gender	1.069	0.935118011	Livestock size TLU	1.991	0.502333329
Age	4.973	0.201066232	Access to credit	1.092	0.915987795
Education	2.353	0.424910484	Access to market	1.828	0.547183553
Family Size	1.114	0.89742594	Access to information	1.195	0.836551556
Farming Exp	5.437	0.183914935	Access to Extension	1.125	0.888576422
Mean VIF |	2.204				

Table 3. Variables, descriptions, values, and hypothesized effects of adaptation decisions in the study area

Explanatory variables	Description	Values	Expected Sign
Gender	Dummy	1=male, 0=female	±
Age	Continuous	Years/number	±
Literacy status	Continuous	1 if the farm household can read and write, and 0 otherwise	+
Family size	Continuous	Number of household members living within the family	+
Farming experience	Continuous	Years/number	+
Landholding	Continuous	Hectares	+
Livestock holdings	Continuous	Number	+
Total annual income	Continuous	Income in Birr	+
Distance to market	Continuous	Measured in walking hours	-
Access to extension	Dummy	1=yes, 0= no	+
Information access	Dummy	1=yes, 0= no	+
Access to credit	Dummy	1=yes, 0= no	+
Agroecological zone	Categorical	0=highland, 1=midland, 2= lowland	±
Adaptation strategies	Categorical	0 = no adaptation options used; 1 = adjusting planting dates; 2 = improved seed; 3 = SWC; 4 = irrigation. 5=livelihood diversification 6=crop diversification	

3. RESULTS AND DISCUSSION

3.1 Demographic Characteristics of Sample Households

From the total of 366 participants, 84.7% were male and 15.3% were from female-headed households. Of the sampled households, about 25.7% were illiterate, and 74.3% could read and write. The mean age of the respondents was 50.75 years, with a standard deviation of 11.09. The minimum and maximum ages were 29 and 74, respectively. During the study period, 21.6% were under 40 years of age, 59.8% were in the range of 41–60 years, and 18.4% were above 65 years (Table 4). Highland agroecology scored the highest average family size (5.74), followed by lowland and midland agroecologies. Smallholder farmers in the highland area hold relatively the highest landholding size, livestock production farm (TLU), and experience. The landholding size of the farmers ranged from 0.125 ha to 6 hectares. This study found that households in lowland agroecology had to travel on average two hours and forty minutes to savings and credit institutions, schools, veterinary services, markets, and health centers, compared to highland households.

Table 4. Demographic and socioeconomic characteristics of the household

		Highland	Midland	Lowland	Total	Percentage
Sex	Male	102	66	148	310	84.7
	Female	19	11	26	56	15.3
Age	20-40	16	17	46	79	21.6
	41-60	79	40	121	219	59.8
	>61	26	12	30	68	18.6
Education	Illiterate	24	23	47	104	25.7
	Read and Write	97	48	127	262	74.3
Average family size		5.74	5.52	5.67		
Average farming experience		27.88	25.7	24.95		
Landholding Size/hectare		2.1	1.67	1.42		
Livestock holding TLU		11.41	8.13	6.48		
Distance to credit/savings		90	150	160		
Distance to market		86.53	150	160		

3.2 Smallholder Farmers' Adaptation Strategies to Climate Change and Variability

Adaptation measures have been implemented to alleviate current climate change-related threats. Farmers in different agroecologies likely adopt different adaptation options to address climate change impacts (Kassie et al., 2015). Like any other area of the country, smallholder farmers in the Jemma sub-basin implement diverse adaptation measures to mitigate climate change, such as adjusting planting dates, using improved seeds, diversifying livelihoods, conserving soil and water, utilizing irrigation, and crop diversification (Figure 2). According to the descriptive statistics, altering planting dates (83%) was the most common adaptation strategy in the lowland area. However, 57.7% of households in the lowland and 33.3% in the highland areas practice soil and water conservation as an adaptation strategy. In contrast, 47.7%

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of midland and 29.5% of highland households utilize improved seeds. The study also found that 46.4% of lowland and 33.3% of highland households adopt livelihood diversification as a strategy. Selling firewood, local drinks, daily labor, and operating small-scale businesses are typical ways for farmers with modest landholdings and large families to diversify their incomes.

Adjusting planting dates (6.8%) and soil and water conservation (8.9%) were the least practiced adaptive responses by farmers in highland and midland agroecology. Crop diversification is a widely practiced adaptation strategy in highland areas of the study area; however, this result contradicts the previous finding by Chemeda et al. (2023) stated that crop diversification is mostly practiced in the lowland areas. According to key informants and focus group participants, crop diversification was practiced to minimize the potential damage of crop failure due to climate variability extremes, insects, pests, and diseases. Irrigation is the second most highly practiced adaptation strategy in the highland areas of the Jemma sub-basin, accounting for about 50% of highland and 36% of lowland households practicing small-scale irrigation in their locality. According to key informants and focus group participants, improved seeds, crop diversification, and irrigation are the main adaptation strategies, along with coping mechanisms to lessen the negative effects of climate change in the study area.

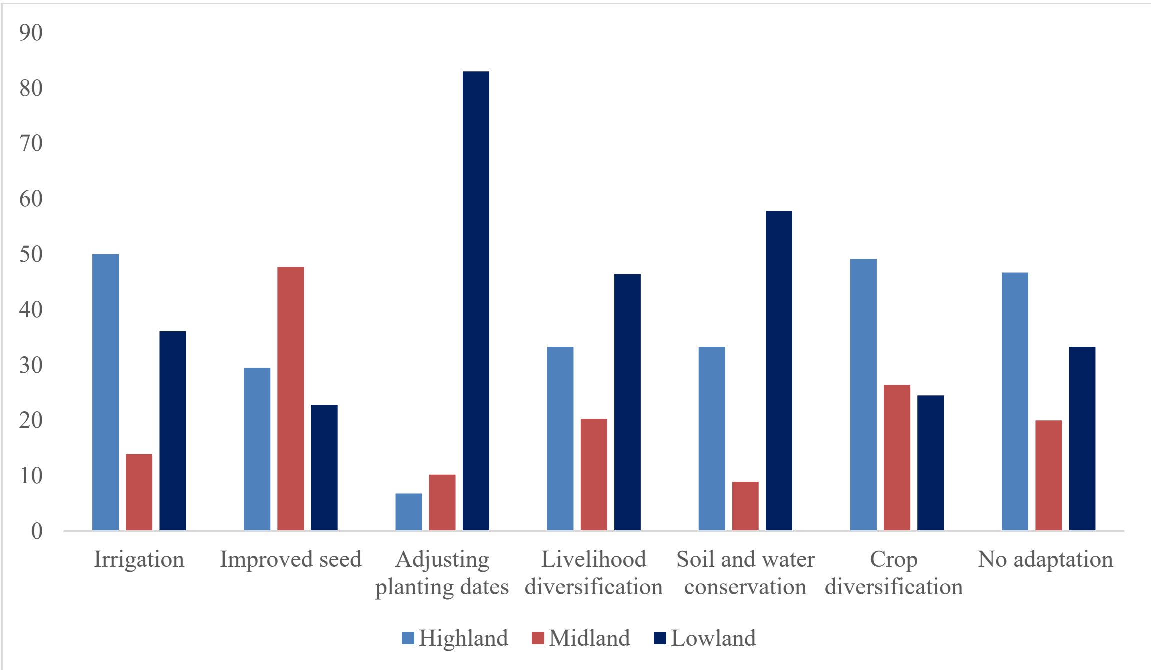

Figure 2. Distribution of farmers' adaptation measures by agroecology

3.3 Comparative Analysis Between Adopters and Non-Adopters

The statistical analysis reveals a significant difference ($p<0.05$) in the mean age of household heads between adopters and non-adopters of adaptation options (Table 5). The average family size (5.66) was higher than the national rural average of 5.13(t (366) $p < 0.05$) and the regional rural average of 4.63(t (366) $p<0.05$ (CSA 2014:13 20). Furthermore, the mean family size for non-adopter households and adopters of soil and water conservation practices is 4.47 and 5.97, respectively. The mean difference in family size among the groups is statistically significant ($p<0.000$). The average total landholding per household was 1.69 ha (0.32 ha per capita), and the highest and lowest mean TLU were recorded in the highland (20.57) and midland (2.2) agroecologies. Farming experience of 26.07 years with a standard deviation of 12.36, and Eth. Birr 74806.20 estimated total annual income for the year 2024.

It is also reported that 85.6% of households adopting SWC measures are male-headed, whereas 40.0% of non-adopters of any adaptation options are female-headed. The Chi-square test shows that differences in the gender of the household head are statistically significant ($p<$ 0.001) among adopters and non-adopters of any adaptation options. Around 44%, 86.1%, 78.1%, and 53.6% of the respondents had access to credit, information, extension services, and the market. Agroecologically, 53.3%, 80%, and 66.7% of highland, midland, and lowland households adopt different adaptation strategies (Table 6).

3.4 Determinants of Farmers' Choices of Adaptation Strategies to Climate Change

Agroecology: The model results showed that farming in lowland areas statistically significant and positive effect on the likelihood of adjusting planting dates and pursuing livelihood diversification, both at a significance level of 5% each. Marginal effect estimates suggest that being a lowland farmer increases the probability of implementing adjusting planting dates by 17.2% and livelihood diversification by 6.25%. However, farming in lowland areas significantly reduces the probability of using improved seed and crop diversification by 8.8% and 1.6%, respectively. In contrast, adjusting planting dates and crop diversification are positively related but not significant in the midland agroecology of the study area. However, living in the midland can increase the probability of using improved seeds by 6.9% at $p < 0.05$ compared to the reference category. The difference might be attributed to soil, climate, other natural resources, and climate-related stress experiences. Irrigation and crop diversification strategies are widely considered adaptation options in highland agroecology to cope with the risk imposed by climate change and variability. This might be due to the high irrigation potential in highland agroecology.

Gender of the Household Head: The gender of the household head is one of the significant variables influencing farmers' overall preference for adaptation strategies. Various studies showed that female-headed households may hurt the implementation of soil and water conservation measures due to limited access to information, land, and other resources (Atinkut & Mebrat, 2016; Abaje et al., 2014). This study also shows that male-headed households practiced significantly different adaptation strategies. Being a male-headed farmer increases the odds of adjusting planting dates, using improved seed, soil, and water conservation, and diversifying livelihood by 4.7, 2.2, 3.6, and 4.3% at $p<0.05$, respectively. The potential reason is that those require relatively better skills and manpower. Moreover, female-headed households are more likely to use common adaptation methods than male-headed households, such as selling alcohol and participating in petty trades.

Table 5. Differences of continuous explanatory variables between adopters and non-adopters using one-way ANOVA

		No adaptation	Adjusting Planting dates	Improved seed	SWC	Irrigation	Livelihood Diversification	Crop diversification
Age of HH	*Mean*	55.40	59.29	44.45	44.44	56.00	47.30	56.81
	SD	14.94	9.31	10.50	7.07	8.19	9.44	9.79
Family size	*Mean*	4.47	5.66	5.02	5.97	5.19	6.36	5.43
	SD	0.92	1.25	1.29	1.35	1.41	1.51	1.20
Farming Experience	*Mean*	31.87	36.12	19.70	19.64	27.17	23.32	32.26
	SD	15.68	9.92	11.29	8.51	12.20	11.06	11.32
Landholding size	*Mean*	1.68	1.52	1.66	1.55	1.90	1.58	2.17
	SD	0.69	0.48	0.74	0.62	0.68	0.65	0.51
Livestock in TLU	*Mean*	6.56	7.82	8.28	7.82	10.51	7.73	10.3
	SD	3.27	3.14	4.73	4.42	5.38	4.05	5.03
Distance to market	*Mean*	132.0	170.8	138.4	146.3	125.8	143.1	126.8
	SD	42.12	23.80	35.57	43.33	48.54	41.53	40.61

Table 6. Differences in dummy explanatory variables for the adopter and non-adopter households

Variables		No Adaptation	Adjusting planting dates	Improved seed	SWC	Irrigation	Livelihood diversification	Crop diversification	Percentage	Chi-square	Sig
Agroecology	Highland	46.70	6.80	29.50	33.30	50.00	33.30	49.10	33.10	79.299	0.000
	Midland	20.00	10.20	47.70	8.90	13.90	20.30	26.40	19.40		
	Lowland	33.30	83.00	22.70	57.80	36.10	46.40	24.50	47.50		
Gender	Female	40.00	10.20	13.60	14.40	11.10	17.40	17.00	15.30	9.241	0.160
	Male	60.00	89.80	86.40	85.60	88.90	82.60	83.00	84.70		
Access to credit	NO	86.70	88.10	22.70	78.90	2.80	27.50	73.60	56.00	140.09	0.000
	Yes	13.30	11.90	77.30	21.10	97.20	72.50	26.40	44.00		
Access to information	NO	60.00	8.50	9.10	16.70	2.80	11.60	17.00	13.90	33.891	0.000
	Yes	40.00	91.50	90.90	83.30	97.20	88.40	83.00	86.10		
Access to Market	NO	46.70	79.70	59.10	56.70	16.70	33.30	18.90	46.40	66.587	0.000
	Yes	53.30	20.30	40.90	43.30	83.30	66.70	81.10	53.60		
Extension service	NO	60.00	16.90	9.10	12.20	5.60	47.80	20.80	21.90	55.581	0.000
	Yes	40.00	83.10	90.90	87.80	94.40	52.20	79.20	78.10		

Age of the Household Head: The parameter estimation result shows that age had a positive and significant correlation with adjusting planting dates, the use of irrigation, and crop diversification at $p<0.05$ and $p< 0.01$, respectively. This means that as age increases by a year, the use of adjusting planting dates, irrigation, and crop diversification will increase by 2.17, 1.43, and 6.4%. Previous study results by Molla et al. (2023) also show, a one-year increase in age will raise the chance of adjusting planting dates by 4.6% in northwestern Ethiopia. Ainembabazi & Mugisha (2015) also noted that households that have long experience had a higher likelihood of adopting climate change adaptation strategies. According to Chemeda et al. (2023), as age rises by one year from the average, the probability of employing adaptation techniques like tree planting, increased crop variety, crop type diversification, agroforestry, and small-scale irrigation drops by 2.7%, 3.6%, 3.7%, 2.1%, 3.4%, and 4.1%, respectively.

In contrast, age negatively correlates with soil and water conservation and livelihood diversification activities. A one-year increase in age will decrease the probability of using soil and water conservation by 8.9 times and livelihood diversification by 4.2 times for households in the base category. It can be concluded that these activities are more labor-intensive, and younger households are more likely to adopt soil and water conservation and livelihood diversification. This result is also in line with (Atinkut & Mebrat, 2016; Asfaw et al., 2019; Amare & Simane, 2017; Belay et al., 2017) who found that younger households are expected to practice soil and water conservation adaptation measures than older ones.

Education: Higher levels of education are believed to be associated with access to information about improved technologies and productivity outcomes (Norris & Batie, 1987). Evidence from previous sources indicates there is a positive relationship between the education level of the household head and the adoption of improved technologies and adaptation to climate change (Mossie, 2022). The educational level of household heads was hypothesized to be a significant factor in coping and adapting to climate change. This is because higher levels of education are more likely to lead to a better understanding of the impacts of climate change and strategies to mitigate them. The result shows that education has a positive and significant relationship with all adaptation strategies, except irrigation. An increase in education level by one year increases the likelihood of adjusting planting dates, using improved seed, soil and water conservation, livelihood diversification, and crop diversification by 4.42, 3.35, 27.59, 10.54, and 4.27% (at 1%, 5%, and 10% significance levels), respectively. The finding is consistent with a previous study by Boka (2025), a one-year increase in education will increase the likelihood of adjusting planting dates by 27.6% in the Arisi Zone. The reason may be that educated farmers anticipate the adoption of new technologies due to their awareness of the potential benefits of adaptation measures (Alemayehu & Bewket, 2017; Chalchisa & Sani, 2016).

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Table 7. Parameter estimates of the multinominal logit climate change adaptation model

Variables	Adjusting planting dates		Improved seed		Soil and water conservation		Irrigation		Livelihood diversification		Crop diversification	
	Coefficient	P value	Coefficient	P value	Coefficient	P value	Coefficient	P value	Coefficient	P value	Coefficient	P value
Agroecology												
Midland	1.8664	0.234	0.8464*	0.057	-0.6302	0.670	0.9534	0.550	-0.1155	0.937	1.6938	0.240
Lowland	3.8952**	0.013	0.1018	0.947	0.4206	0.775	3.2965**	0.040	1.4868	0.311	2.0181	0.164
Gender	2.6087**	0.013	2.3815**	0.024	2.4736**	0.011	1.0888	0.363	2.4807**	0.014	1.5100	0.118
Age	0.1461*	0.052	0.0961	0.354	-0.0569	0.056	0.3605***	0.002	-0.0988	0.319	0.1992**	0.040
Education	3.3699*	0.059	4.4340**	0.014	5.7223***	0.002	2.9970	0.102	3.2076*	0.065	3.2606*	0.057
Family Size	1.6161***	0.001	1.2315**	0.016	1.9275***	0.000	1.2603**	0.019	2.072***	0.000	1.291***	0.009
Farming Experience	0.0252*	0.078	-0.0715	0.449	-0.0455	0.608	-0.2222	0.030	-0.0586	0.514	0.0917*	0.029
Landholding in/ha	-1.4904	0.122	-0.1472	0.879	-0.8791	0.337	-1.3466	0.191	-1.1880	0.193	0.5504	0.530
Livestock/TLU	0.2062	0.206	0.0404	0.801	0.0491	0.754	0.1433	0.385	0.0005	0.997	0.0600	0.689
Total annual income	0.0000	0.764	0.0000	0.513	0.0000	0.510	0.0001*	0.054	0.0000	0.256	0.0000	0.411
Access to credit	0.5143	0.682	2.8767**	0.019	0.5745	0.632	5.5641***	0.001	2.7236**	0.023	0.9714	0.419
Access to Inform.	1.8039*	0.072	1.3188	0.228	0.6925	0.444	2.2673	0.144	2.1070**	0.031	1.4750	0.105
Extension Service	1.6957*	0.061	2.959***	0.003	2.4764***	0.005	3.0510**	0.013	0.4554	0.601	1.7570**	0.045
Access to market	0.6163	0.604	0.2603	0.828	0.6621	0.568	3.1872**	0.016	1.9294*	0.099	2.6734**	0.021
-Cons	-23.735***	0.000	-17.84***	0.004	-17.748***	0.003	-33.817***	0.000	-20.33***	0.001	-23.27***	0.000

Multinominal logistic regression
Number of obs = 366
LR chi2 (84) = 594.37
Prob > chi2 = 0.0000
Log-likelihood =-372.69
Pseudo R2 = 0.4436
***, **, * Significant at 1, 5, and 10% probability levels, respectively

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Table 8. Marginal effects from the multinominal logit of the climate change adaptation model

Variables	Adjusting planting dates		Improved seed		SWC		Irrigation		Livelihood diversification		Crop diversification	
	Dy/dx	P value	Dy/dx	P value	Dy/dx	P value	Dy/dx	P value	Dy/dx	P value	Dy/dx	P value
Agroecology												
Midland	0.0621	0.123	0.0695**	0.027	-0.1656**	0.010	0.0068	0.828	-0.0637	0.189	0.1201	0.028
Lowland	0.1732***	0.000	-0.0880*	0.071	-0.1390**	0.020	0.0874	0.214	0.0625*	0.096	0.0166*	0.070
Gender	0.0476	0.298	0.0226	0.580	0.0361	0.468	-0.0486	0.153	0.0434	0.357	-0.0531	0.208
Age	0.0217	0.533	-0.0028	0.398	-0.0893**	0.026	0.0143***	0.000	-0.0425	0.248	0.0646*	0.054
Education	0.0442	0.040	0.0335	0.542	0.2759***	0.005	-0.0310	0.338	0.1054*	0.081	0.0427	0.038
Family Size	0.0037	0.734	-0.0322***	0.003	0.0452***	0.001	-0.0157*	0.068	0.0569***	0.000	-0.0230**	0.034
Farming Experience	0.0712**	0.021	0.0000	0.989	0.0008	0.820	-0.0071***	0.003	0.0013	0.704	0.0317**	0.031
Landholding in ha	-0.0758**	0.050	0.0466	0.189	-0.0232	0.611	-0.0366	0.141	0.0548	0.158	0.1316***	0.000
Livestock /TLU	0.1213**	0.042	-0.0016	0.728	-0.0024	0.709	0.0412**	0.018	-0.0085	0.108	-0.0019	0.695
Total annual income	0.0000	0.188	0.0376*	0.095	0.0000	0.675	0.0815***	0.001	0.046**	0.026	0.0000	0.955
Access to credit	-0.0754**	0.029	0.0802***	0.006	-0.1629***	0.000	0.1632***	0.000	0.1040***	0.002	-0.0800**	0.011
Access to Information	0.0408	0.042	-0.0080	0.885	-0.1169**	0.043	0.0297	0.607	0.0845	0.151	0.0024	0.958
Extension Service	-0.0086	0.829	0.0839***	0.057	0.1070**	0.033	0.0628	0.100	-0.1937***	0.000	-0.0100	0.809
Access to market	-0.0654*	0.072	-0.0956***	0.009	-0.0860*	0.076	0.0739**	0.015	0.0696	0.100	0.1350***	0.001

Family Size: Parameter estimation results show that family size has a significant and positive impact on the implementation of various climate change adaptation measures such as soil and water conservation, irrigation, livelihoods, and crop diversification ($p < 0.05$). The marginal effect results in Table 7 show that an increase in productive family members increases the probability of implementing soil and water conservation measures and livelihood diversification by 4.52% and 5.69%, respectively. This result is further supported by Gebre et al. (2023) and Belle et al. (2024) stated that larger family sizes and productive household members will increase the likelihood of adopting various labour-intensive climate change adaptation strategies. Hence, household size has a significant association with several adjustment categories. However, this result contradicts Mihiretu et al. (2019) findings stated that larger family sizes were associated with a lower likelihood of adopting certain climate change adaptation strategies due to labour division for non-farm activities to meet consumption needs.

Farming Experience: According to the parameter estimation results, all listed climate change adaptation options correlate with agricultural experience. In particular, as farming experience increases by the year, the practice of adjusting planting dates and crop diversification increases by 7.12% and 3.17%. This means that more experienced farmers are more likely to alter planting dates and crop diversification to adapt to the changing climate, for the reason that farmers with high experience are more likely to have better information about changes in climatic conditions. Farming experience is also positively correlated with soil and water conservation, the use of improved seeds, and livelihood diversification, but not significantly. Previous studies by Kassie (2022) and Kabambe et al. (2020) found that experience often plays a more direct role in implementing climate change adaptation strategies than age. The result by Gebre et al. (2023) found that farming experience increased the likelihood of practicing most adaptation options, while farmer age did not appear to have a significant impact on adaptation. This is because more experienced farmers are believed to have better knowledge of weather information and its impact on agricultural practices.

Landhold Size: Farm size has a positive and significant ($p < 0.001$) relation with implementing crop diversification in the study area. In other words, the probability of practicing crop diversification increases by 13.16% when agricultural land increases by one unit. Farmers with large cultivated areas are likely to have many agricultural plots with different physical and chemical soil properties that have been differentially affected by climate change (Amare & Simane, 2017b). Perhaps it is the fact that has reassured farmers that they do not have to worry about drought-tolerant varieties, crop rotation, and changing planting dates to reduce the effects of climate change and variability. Landholding size is negatively and significantly associated with the adoption of livelihood diversification, adjustment of planting dates, and soil and water conservation in response to climate variability and changes in the study area. An increase in cultivated area would reduce the likelihood of using livelihood diversification and soil and water conservation by 5.48% and 12.8%, respectively. In addition, adjusting planting dates and irrigation practices will also decrease by 7.58%. This could be because farmers with a large cultivated land are less afraid of taking climate change risks than their counterparts.

The Number of Livestock (TLU): TLU had positive relationships with adjusting planting dates and irrigation. The marginal effect results show that an increased number of TLU would increase the likelihood of adjusting planting dates and irrigation by 12.13% and 4.12%, respectively. A potential reason could be related to the fact that livestock play a vital role from land preparation to planting and harvesting. This result aligns with Belay et al. (2017) and Molla et al. (2023) stated that livestock production has a positive association with adjusting planting dates. Another research result by Mume et al. (2023) indicates that each additional TLU increased the probability of adopting small-scale irrigation by 7.8% in the Kersa district of the Oromia region. In contrast, livestock ownership showed a significant and adverse relationship with soil and water conservation and improved seed. In other words, a unit change in TLU will reduce the probability of using improved seed and soil and water conservation by 0.16% and 0.24%, respectively.

Total Annual Income: According to the model result, total annual income has positive and significant correlations with all adaptation strategies. The marginal effect result in Table 6 shows that an increase in household income by one birr can increase the probability of using improved seeds, irrigation, and livelihood diversification by 3.76%, 8.15%, and 4.65%, respectively. The reason may be that high-income farmers have a higher chance of investing more time in agricultural tasks to reduce the impacts of climate change and variability. The result is further supported by previous studies by Marie et al. (2020) and Destaw et al. (2021) also found that the income was a significant factor influencing farmers' choice of adaptation strategies. A study in Odisha, India, shows that as farm income increases by a unit, the probability of adopting climate-smart agriculture, such as crop rotation and integrated soil management, increases by 27-45% (Ranjan et al., 2023). However, the result contradicts Feleke et al. (2016), which showed that income significantly and negatively impacted households' adaptation strategies.

Access to credit: enhances farmers' financial resources and their ability to reduce transaction costs associated with various adaptation measures (Mihiretu et al., 2019; Belay et al., 2017). The parameter estimate shows that improved seed, irrigation, and livelihood diversifications are positively and significantly correlated with access to credit at $p<0.001\%$ and $p<0.05\%$ significance levels. In other words, households with better access to credit are more likely to use improved seeds, irrigation, and diversify their livelihoods by 8.04%, 16.32%, and 10.4%, respectively. This can be explained by the fact that credit availability reduces liquidity constraints and encourages the adoption of improved seed, irrigation, and livelihood diversification. In other words, addressing household cash shortages through credit can motivate farmers to purchase improved seeds, generators, fertilizers, pest and disease chemicals, and to engage in small-scale trading activities. This highlights the important role of increased financial sector support in promoting the use of improved seeds, irrigation, and livelihood diversification as climate change adaptation strategies. Research by Elias et al. (2017) indicates that access to credit encourages irrigation adoption in Ethiopia. Access to credit can increase irrigation adoption by 7% (Ndiwa et al., 2024) and nearly twice as much compared to households without credit access (Olutumise, 2023). However, these findings contradict those of Atube et al. (2021), who found that access to credit negatively affects farmers' adaptation strategies.

Extension Service: The advisory service is an important source of information on the effects of climate change and adaptation strategies. Therefore, it is hypothesized that household heads who have access to extension services will increase the probability of implementing different adaptation strategies. The result shows that the extension service significantly increases the likelihood of using soil and water conservation technologies (p=0.01) and improved seeds (p=0.1) as an adaptation strategy. This means farmers with better access to extension services increase the likelihood of adopting soil and water conservation measures by 10.7 times and improved seeds by 8.39 times. Furthermore, access to extension services is a significant factor in the change in planting dates at the p=0.05 level. The parameter estimate also shows a positive relationship between extension service and adjusting planting dates, irrigation, and crop diversification. This implies that farmers with better access to information about climate change are more likely to adopt adaptation measures. This finding aligns with several other studies showing that farmers who obtained information from extension workers tend to be more aware of the climatic situation and corresponding responses (Megersa et al., 2022; Atinkut & Mebrat, 2016).

Access to Information: Climate information is a crucial enabler in adapting to climate change and managing climate-related risks by smallholder farmers (Ngigi & Muange, 2022). The availability of better climate information helps farmers make comparative decisions among alternative adaptation practices and hence choose the ones that enable them to cope better with climate change. The parameter estimate result indicates that access to climate information has a positive influence on all adaptation strategies and is significantly associated with adjusting planting dates and diversifying livelihoods. Specifically, being well-informed about rainfall and temperature fluctuations will increase the likelihood of adjusting planting dates and livelihood diversification by 4.7 and 8.45%, respectively.

Access to Market: Market access was positively and significantly associated with adopting irrigation, livelihood, and crop diversification. The marginal effect results indicate that proximity to the market center significantly increases the probability of adopting irrigation, livelihood diversification, and crop diversification by 7.39, 6.9, and 13.5%, respectively. This is because locating near the market center increased the opportunity to engage in small-scale trade and daily labor activities. It also helps farmers to sell their irrigation products, purchase fertilizers and pesticides, and improve crop varieties easily, as compared to others. Farmers from far away face the problem of selling their irrigation products. Farmers with access to markets will increase the probability of using different adaptation strategies such as irrigation, crop diversification, and improved crop varieties (Upendram et al., 2023; Destaw et al., 2021). Belay et al. (2017) also found that easier market access boosts the likelihood of practicing crop diversification.

4. CONCLUSION

This study investigated the adaptation strategies adopted by smallholder farmers and factors influencing their implementation using a multinominal logit model in the Jemma sub-basin of Ethiopia. The findings revealed that smallholder farmers employed a range of adaptation measures to address the impact of climate change across different agroecological zones. These strategies included adjusting planting dates, soil and water conservation measures, irrigation, adopting improved seed varieties, diversifying livelihoods, and practicing crop diversification. However, the selection of adaptation measures by smallholder farmers was influenced by several key explanatory variables. The multinominal logit (MNL) model shows that out of 13 independent variables included in the analysis, agroecology gender, education, family size, total annual income, access to credit, and access to information positively influenced the decision to adopt a higher number of adaptation strategies. The model result further showed that male-headed households and the educated are more likely to adopt soil and water conservation, irrigation, livelihood, and crop diversification strategies in response to climate change/variability. In addition, households with higher landhold size and family size had a better chance of adopting livelihood diversification and soil and water conservation. The study found that improved access to credit and easy access to the market enable households to pursue livelihood diversification, improved seed, and irrigation. This implies that credit market imperfections can hinder capital-constrained farm households from engaging in small-scale irrigation in the study area.

Overall, the significant factors influencing the adoption of various adaptation strategies were different, highlighting the need to consider the unique characteristics of the respective strategies. Moreover, creating opportunities for non-farm income sources is important as this helps them to engage in those activities that are less sensitive to climate change. Empowering female-headed farmers by creating a conducive environment to access inputs, credit, training, and extension services related to climate change and agriculture should also be a key area for policymakers. In general, future policy should focus on providing adaptation options through agroecology-based research results, developing and promoting drought-tolerant crop varieties, ensuring access to low-interest credit, and providing adequate extension services.

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