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Determinants of agroforestry-based smallholder farmers' choices of adaptation to climate change and variability in southern Rift Valley Escarpments of Ethiopia

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Abstract

Climate change poses substantial risks to agriculture and food security in Ethiopia, particularly among smallholder farmers in the southern Rift Valley. This study investigates the key determinants influencing adaptation choices among farmers in the Gedeo Zone. Employing an explanatory research design, the study integrates both quantitative and qualitative methodologies. A structured questionnaire was administered to a sample of 384 households across three districts, complemented by focus group discussions and key informant interviews to enrich qualitative insights. Quantitative data were analyzed using descriptive statistics and a propensity score matching (PSM) framework, combined with a binary logistic regression model to estimate treatment effects and control for confounding variables. Concurrently, qualitative data were examined through thematic analysis, where emergent patterns and recurrent concepts were systematically identified, categorized, and synthesized into coherent thematic constructs. Findings reveal that the majority of farmers in Kochere (65.67%) and Wonago (62.16%) districts do not adopt agroforestry, whereas Yirgachefe district exhibits a higher adoption rate (51.08%). Factors significantly influencing agroforestry-based adaptation choices include household age, gender, farm size, access to basic services, participation in local institutions, and wealth and asset status. The study demonstrates that agroforestry substantially enhances climate resilience, with 59.75% of adopters reporting improved resilience compared to only 5.78% of non-adopters (t-value = 14.32). This proven the synergy between agroforestry and climate resilience firmly establishes it as a strategic pillar of sustainable rural development. The results underscore the urgent need for targeted policy interventions and community-driven strategies to promote agroforestry, thereby fostering resilience, sustainability, and food security in the Gedeo Zone.

Keywords/Phrases: Adaptation, Agroforestry, Climate change, Ethiopia, Gedeo Zone

1 Introduction

Ethiopia is among the most climate change-vulnerable countries, experiencing rising temperatures, erratic rainfall, and increasingly severe weather events. These changes have significantly impacted agricultural productivity, leading to food insecurity and poverty (Abebe *et al*., 2018; Asnake, 2021; Deressa *et al*., 2019). In the southern Rift Valley escarpments, smallholder farmers, heavily reliant on rain-fed agriculture, are particularly at risk. Their vulnerability underscores the urgent need for effective adaptation strategies (Abebe *et al*., 2018; Mekonnen *et al*., 2016). Agroforestry, a practice integrating trees into farming systems, offers a promising means to enhance resilience to climate challenges (FAO, 2019). By combining agricultural and forestry practices, agroforestry mitigates the impacts of climate variability while supporting livelihoods (Regassa *et al*., 2020).

Agroforestry has deep historical roots in Ethiopia, originating approximately 7000 years ago and evolving into a prominent farming practice in most regions except the semiarid lowlands (Sileshi, 2016). In areas such as Gedeo, traditional agroforestry features dense arrangements of trees, shrubs, and crops, ensuring continuous plant cover. This system provides immediate agricultural and social benefits, with climate mitigation as a valuable secondary effect (Ogle *et al*., 2014). Such practices enhance crop yields (Amare, 2017) and are regarded as exemplary land-use models (Gebrehiwot *et al*., 2014).

Climate change adaptation is critical for farming communities such as those in the Gedeo Zone, as it enhances their resilience against the adverse effects of climate variability (Fissha, *et al*., 2019). Agricultural practices that incorporate adaptive strategies can significantly improve food security and livelihoods by mitigating risks associated with unpredictable weather patterns (Lobell *et al*., 2014). Additionally, diversifying crops and improving water management are essential for maintaining productivity in the face of changing climatic conditions (Mastrorillo *et al*., 2016). Community engagement in adaptation strategies fosters local knowledge and resource utilization, which is vital for sustainable development (Kassam *et al*., 2020). Ultimately, effective adaptation not only supports agricultural sustainability but also preserves cultural heritage and community identity in the face of environmental challenges (Adger *et al*., 2018).

While agroforestry's potential for climate change adaptation is widely recognized (Adimassu *et al*., 2014; Debele *et al*., 2018; Regassa *et al*., 2020), critical research gaps persist. Limited studies have explored factors influencing smallholder farmers' adaptation decisions in the south-eastern Rift Valley escarpments (Gebrehiwot *et al*., 2014; Muluneh *et al*., 2015). Existing research often generalizes agricultural adaptation strategies, overlooking the unique dynamics of agroforestry systems in this specific context. For instance, Kessler (2014) emphasize the need for focused studies on adaptation strategies tailored to agroforestry, especially in distinct regions like the northern Ethiopian highlands.

Moreover, the lack of studies addressing spatial and temporal variations in crop diversity within agroforestry systems limits our understanding of adaptation strategies (Deressa *et al*., 2019; Hagos *et al*., 2011; Tesfaye, 2014). Tesfaye and Bongers (2014) put the need for further investigation on determinants agroforestry-based smallholder farmers' adaptation decisions in response to climate change and variability. These gaps highlight the necessity of localized research accounting for ecological and socio-economic variations in the south-eastern Rift Valley (Deressa *et al*., 2019; Gebreegziabher *et al*., 2010).

This study seeks to address these gaps by investigating the determinants of smallholder farmers' agroforestry adaptation decisions in the Gedeo Zone. Employing Propensity Score Matching (PSM) to account for selection bias and unobserved confounders, this research provides robust insights into agroforestry's role in enhancing resilience to climate change. By filling these critical gaps, the study contributes valuable knowledge to the discourse on sustainable land management and adaptation strategies for vulnerable farming communities in Ethiopia.

2 Materials and Methods

2.1 Description of study area

This study was conducted in selected districts within Gedeo Zone, located in Southern Ethiopia Regional State. Geographically, the Zone lies north of the equator, between 5°53'N to 6° 27'N latitude and from 38° 8' to 38° 30'east longitude (Negash, 2010). It is located along on the main highway connecting Addis Ababa near the Kenya border, 365 kilometers south of Ethiopia's capital city Addis Ababa. Slope gradient reaches up to 70% in some areas and almost 50% of the landscape is steep, with slope gradient above 10 % (Mesele, 2011; MCTA, 2020). The majority of the soil type in the area is Nitosol (Abiyot, 2013), typically made up of volcanic rocks. The Zone has three agro-ecological zones whose mid altitude agro-ecology occupies the largest area (62.2%) followed by high land (37.1%) and low altitude (0.7%) (Bogale, 2007). The study districts, namely Kochere, Yirgachefe and Wonago are among the districts in the Gedeo Zone Southern Ethiopia regional state (Figure 1). Kochere district is found between 6°09' N latitude and 38°'16'E longitude. Elevations range from 1,500 to 3,100 meters above sea level (masl), and the study area comprises two agro-

climate zones: Dega (with elevations between 2,300 and 3,700 masl, accounting for 26%) and Weyna Dega (ranging from 1,500 to 2,300 masl, constituting 74%) according to Yibrah (2014). The average annual temperature falls between 25°C and 31°C, while the annual rainfall ranges from 1,000 to 1,200 millimeters, as reported by Adugna (1998).

Yirgachefe district is located between 6°09' and 6°32' N and 38°08' and 38°32' E, with an altitudinal range of 1501–2500 masl (Negash 2007). The annual rainfall ranges between 1200 and 1800mm, with a bimodal distribution, and the mean annual temperature varies from 15°C to 20°C (Asnake, 2021). Wonago district is found between 6°20' E and 6°32' E, and 38°14' N and 38°24' N, with an undulated type of landscape and an altitude ranging from 1601 to 2875 masl. The district receives rainfall of 800 to 1400mm per annum and annual temperatures ranging from 11°C to 29°C (Negash 2007). All study districts are categorized as mid and highlands based on elevation, with a range of 1500–3700 masl.

2.2 Study site selection

The three research districts, namely Kochere, Yirgachefe, and Wonago, were purposefully selected to characterize the agroforestry-based adaptation options to climate change and variability in these districts. This selection was driven by the high prevalence of indigenous agroforestry practices in the coffee-producing belt of the Zone. From each district, three kebeles (the smallest administration unit in Ethiopia) were randomly chosen: two from the midlands and one from the highlands. In total, the study included nine kebeles of which six are from the midlands and three are from the Highlands. Accordingly, Jeldo and Anchabi from the midland, as well as Gololicha kebele from the highland of the Kochere district (symbolizing Woina dega and dega,

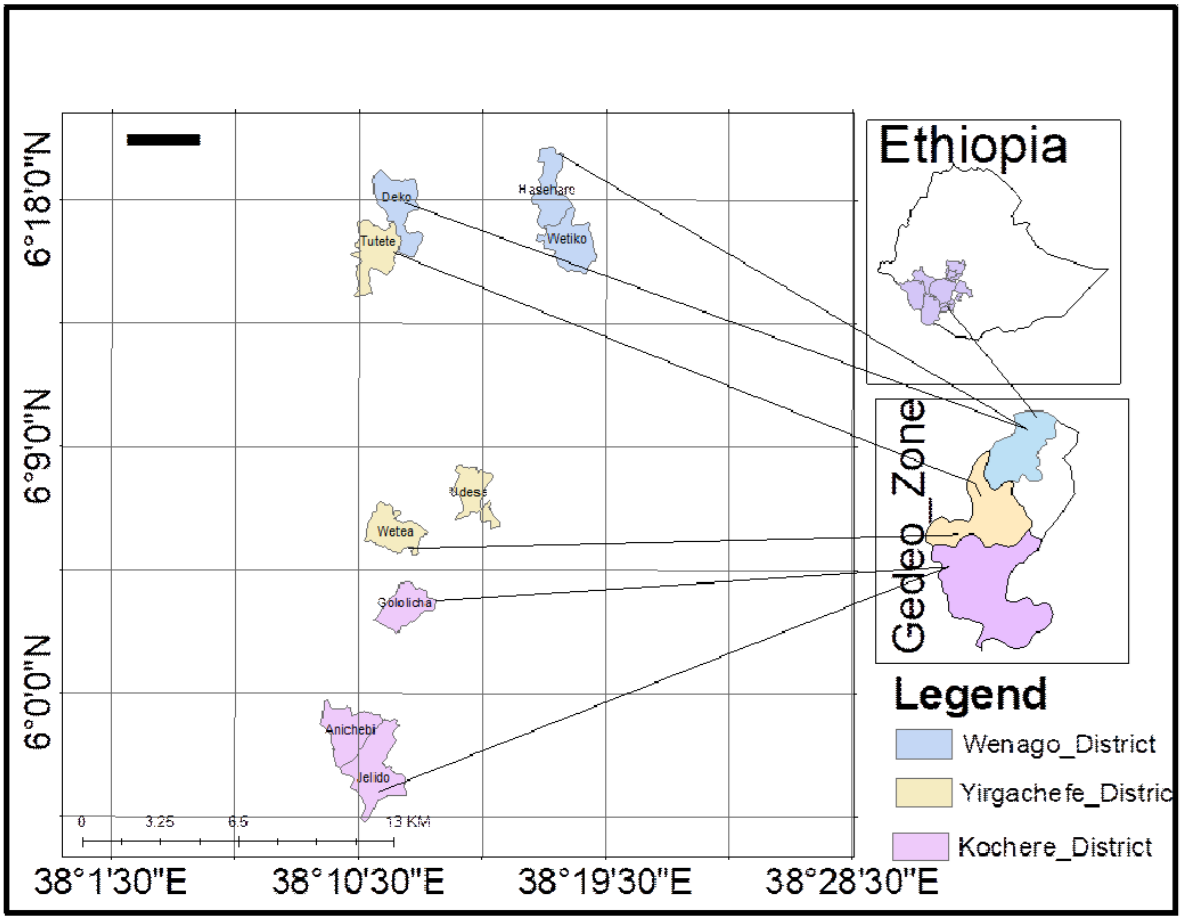


Figure 1. Location map of study area

respectively), were chosen. Similarly, in the Yirgachefe district, Tutit and Wote (from the midlands) and Udesa kebele (from Woina dega) were included. Likewise, Deko and Hase Haro (from the midlands) and Wotiko kebele from the Woina dega were randomly selected in the Wonago district, with the expectation that agroforestry-based adaptation options would vary across different kebeles in diverse agro-ecologies.

2.3 Research Design

For the purpose of this study, an explanatory research design was employed to explain how independent variables (determinant factors) determine dependent variable (farmer's agroforestry adaptation status).

2.4 Research Approach

To achieve the study's objective, the researcher used a mixed-methods approach, combining quantitative and qualitative methods. Quantitative data were gathered through structured surveys of smallholder farmers, covering demographics, farm practices, agroforestry adoption, climate change perceptions, and adaptation strategies. Qualitative data were collected via in-depth interviews and focus group discussions as a subset of the surveyed farmers. This comprehensive approach provided a deeper understanding of the factors influencing farmers' adaptation choices.

2.5 Data type and sources

This study used both primary and secondary data. Primary data were gathered through household surveys, key informant interviews, and focus group discussions. Secondary data were collected from government reports, academic journals, published and unpublished materials (theses, dissertations), and websites. By triangulating these diverse sources, the study aims to comprehensively understand the factors influencing smallholder agroforestry farmers' adaptation decisions to climate change and variability in the Gedeo Zone, southern Ethiopia.

2.6 Sampling techniques and sample size determination

Multiple-stage stratified sampling methods were used in the study. First, districts were selected due to high climatic change and variability. Second, the district is grouped by their agro-ecology (strata) on the basis of their elevation, where 1500–2300 masl is categorized as midland and above 2300 masl is categorized as high land. Third, kebeles were chosen from each agro-ecology stratum for data uniformity, and finally, households were randomly selected from selected kebeles on the basis of their wealth status using proportional sampling. The wealth status of the sample households were stratified into three groups based on well-defined local criteria for the study area using key informants: rich locally known as (dureessa), medium (oddicha), and poor (hiyeessa). Proportional sampling was then employed to take sample sizes from each wealth category. This is because smallholder farmers' agroforestry-based adaptation options vary in reference to demographic and socioeconomic factors.

The sample size of sampled households was determined following Yemane (1967) sampling techniques as follows:

$$n = \frac{N}{1+N(e)^2} = \frac{9662}{1+9662(0.05)^2} = \frac{9662}{1+9662(0.0025)} = \frac{9662}{25.155}$$

$$= 384$$

Where n, N, and e represent the sample size (number of respondents), total number of households and level of precision (allowable error, 5%), respectively.

For sample size allocation at kebele level, the proportional allocation formula was used as:

$$n_i = \frac{N_i * n}{N}$$

Where; n_i = the sample size proportion of each kebele, N_i = the population proportion in the stratum (kebeles), n = the sample size of the districts, and N = the total population of the districts.

Table 1. Total household and sample size of the study area

Name of Districts	Name of Kebeles	Total Households	Sampled Households	
			Freq.	Percentage
Kochere	Jeldo	1073	43	11.19
	Anchabi	1024	41	10.79
	Gololcha	1253	50	13.02
Yirgachefe	Tutit	801	32	8.33
	Wote	970	39	10.15
	Udesa	1014	40	10.41
Wonago	Deko	1002	40	10.41
	Hase Haro	880	35	9.11
	Wotiko	1645	64	16.66
Total	9	9662	384	100

2.7 Data collection methods

The survey, conducted from August to October 2022, utilized structured questionnaires complemented by focus group discussions (FGDs), key informant interviews (KIs), and observations to gather both quantitative and qualitative data, enabling deeper insights and triangulation. Regassa *et al*. (2020) provided a framework for examining smallholder farmers' climate change adaptation strategies in Ethiopia.

Structured Questionnaire: Quantitative data were collected using a questionnaire initially designed in English, translated into the 'Gede'uffa' language for fieldwork clarity, and later retranslated into English for analysis.

Focus Group Discussions (FGDs): Separate discussions with elders, youth, and women in each Kebele (8–12 participants per group) explored topics such as climate change perceptions, agroforestry adaptation strategies, and determining factors. The sessions were organized around three themes, focusing on farmers' insights into agroforestry practices, their intentions to adopt such practices, crop diversity, and climate adaptation strategies. Each discussion lasted about 90 minutes, during which detailed written notes were taken to document the participants' contributions, as audio recordings were not used.

Key Informant Interviews (KIs): Using snowball sampling (Martin, 1995), 45 key informants (five per Kebele) were selected. Semi-structured interviews focused on climate change prediction, information sources, indigenous tree planting, and a determinant of adaptation was used. Input from district specialists and development agents ensured diversity among respondents. This comprehensive approach provided rich data to analyze smallholder farmers' adaptation decisions to climate change in the Gedeo Zone.

2.8 Methods of data analysis

The study primarily utilized quantitative methods, with descriptive statistics (percentages, means, Chi-squares) analyzed using STATA software version 15.0. A Logit model was also employed for deeper analysis. Qualitative data, obtained through interviews and focus group discussions, were analyzed using thematic analysis involving identification, categorization, and synthesis of recurring idea into coherent thematic constructs. This approach facilitated the recognition of patterns in farmers' adaptation decision. The study references Regassa *et al*. (2020) for smallholder farmers' adaptation strategies and the Food and Agriculture Organization of the United Nations (2019) for insights into agroforestry-based climate resilience in Ethiopia.

2.9 Model specification

Propensity Score Matching (PSM)

Propensity Score Matching (PSM) is a method used to estimate the causal effect of a treatment (in this case, farmers' participation in agroforestry) on an outcome variable (climate resilience). The propensity score is defined as the probability of receiving the treatment given a set of observed covariates. The mathematical derivation of the specified variables was as follows:

Step 1: Define the Model

We define the treatment variable Y_i (FAFAS$_i$) as follows:

Y_i = 1 if farmer i adopts agroforestry; 0 otherwise.

The outcome variable CR (climate resilience) is also binary:

CR$_i$ = 1 if farmer i has climate resilience; 0 otherwise.

Step 2: Logistic Regression for Propensity Score Estimation

The propensity score $e(X_i)$ is modeled using a logistic regression, where X_i represents the vector of independent variables:

$e(X_i) = \mathrm{P}(Y_i = 1 \mid X_i) = 1 \,/\, 1 + e^{(-\eta_i)}$

Where, η_i is given by:
$\eta_i = \beta_\circ + \beta_1$ Agehh$_i$ + β_2 Sexhh$_i$ + β_3 Mshh$_i$ + β_4 Hhfz$_i$ + β_5 Educ$_i$ + β_6 Farmsize$_i$ + β_7 Accessbs$_i$ + β_8 Accessmkt$_i$ + β_9 Agroecology$_i$ + β_{10} Foodsec$_i$ + β_{11} Hhinco$_i$ + β_{12} Participation$_i$ + β_{13} Wealth$_i$

Here, X_i = Agehh, Sexhh, Mshh, Hhfz, Educ, Farmsize, Accessbs, Accessmkt, Agroecology, Foodsec, Hhinco, Participation, Wealth.

Step 3: Estimation of Propensity Scores

Using maximum likelihood estimation, we fit the logistic regression model to obtain the coefficients β_i. The estimated propensity score is calculated as follows:

Fit the Logistic Regression: This yields estimates for $\beta_\circ$, β_1, ... β_{11}.

Calculate Propensity Scores: For each observation, compute: $e(X_i) = \mathrm{P}(Y_i = 1 \mid X_i) = 1 \,/\, 1 + e^{(-\eta_1)}$

Step 4: Matching Process

Following the estimation of the propensity scores, treated units defined as farmers who adopted agroforestry were matched with control units, comprising farmers who did not adopt agroforestry. This matching procedure aims to balance covariates across groups, thereby minimizing selection bias and enabling a more robust estimation of treatment effects.

Table 2. Description of variables and its expected and observed output (sign)

Variables name	Variables code	Measurement	Exp. Sign	Obtained Sign
Dependent variable				
Farmer's agroforestry adaptation options status to climate changes and variability	$FAFAS_i$	Binary (FAFAS i =1 if farmers adapt agroforestry as adaptation options to climate changes and variability, 0 otherwise)		
Outcome variable				
Climate resilience due to agroforestry adaptation	CR	Binary (1 if yes, 0 otherwise)		
Independent variables				
Age of the household heads	Agehh	Continuous categorical variable (0= 20-30 years, 1= 31-40 years, 2 = 41-50 years, 3= 51 - 60, 4= above 60 years old)	+	+
Sex of the household heads	Sexhh	Binary (1 = male, 0 = female)	+	+
Marital status of the household heads	Mshh	Binary with many choice (1 if married, 0 otherwise, 2 if single, 0 otherwise, 3 if divorced, 0 otherwise and 4 if widowed, 0 otherwise)	-	-
Family size of the households	Hhfz	Continuous categorical variable (1 if 6-10, 0 otherwise, 2 if above 10, 0 otherwise)	+	-
Education level of the household heads	Educ	Binary with many choice (1 if illiterate, 0 otherwise, 2 if primary, 0 otherwise; 3 if secondary, 0 otherwise, 4 if certificate, 0 otherwise and 5 if diploma and above, 0 otherwise	+	+
Farm size in ha owned by the households	Farmsize	Binary with many choice (1 if Poor (HH have 0 to 0.5ha), 0 otherwise, 2 if Medium (HH have 0.51 to 1.6 ha), 0 otherwise; 3 if rich (HH have above 1.6 ha), 0 otherwise)	+	+
Access to basic services	Accessbs	Binary (1 if households get adequate access to basic services, 0 otherwise)	+	+
Access to market	Accessmkt	Binary (1 if households have adequate access to market services, 0 otherwise)	+	+
Agro ecology	Agroecology	Binary with many choice (1 if low (if elevation 0 to 1500), 0 otherwise, 2 if Medium (if elevation 1500 to 2300), 0 otherwise; 3 if High (if elevation 2300 to 3100), 0 otherwise)	+	-
Food security status of the households	Foodsec	Binary (1 if hhs are food secured (gets 2100kcal/day/person, 0 otherwise)	+	+
Income of the household heads	Hhinco	Binary (1 if Poor (adult HH earns less than 1.9$), 0 otherwise, 2 if rich (adult HH earns more than 1.9$, 0 otherwise)	+	+
Participation status of the farmers in local institutions	Participation	Binary (1 if the household members have participation in local institution, 0 otherwise)	+	+
Wealth category of the households	Wealth	Binary with many choice (1 if Poor (Hiyeessa), 0 otherwise, 2 if Medium (Oddicha), 0 otherwise; 3 if rich (Dureessa), 0 otherwise).	+	+

3 RESULTS

3.1 Farmer's agroforestry adaptation status to climate changes and variability characteristics

Farmers' agroforestry adaptation status to climate change and variability is detailed in Table 3, along with the characteristics of their districts.

The results presented in Table 3 highlight the adaptation status of farmers to agroforestry practices in Kochere, Wonago, and Yirgachefe districts of the Gedeo Zone. Overall, 58.59% of farmers reported non-adaptation, while 41.41% had adopted agroforestry practices. In Kochere, 65.67% (88 farmers) did not adopt agroforestry, while 34.33% (46 farmers) had adapted. In Wonago, 62.16% (69 farmers) reported non-adaptation, and 37.84% (42 farmers) adopted, suggesting slightly better initiatives or support. Conversely, Yirgachefe recorded a higher adaptation rate, with 51.08% (71 individuals) adopting agroforestry and 48.92% (68 individuals) remaining non-adopters.

Table 3. Summary of farmer's agroforestry adaptation status to climate changes and variability characteristics

Farmer's adaptation status	Districts							
	Kochere		Wonago		Yirgachefe		Mean	
	Freq	%age	Freq	%age	Freq	%age	Freq	%age
Farmers did not adapt agroforestry adaptation options	88	65.67	69	62.16	68	48.92	225	58.59
Farmers adapt agroforestry adaptation options	46	34.33	42	37.84	71	51.08	159	41.41
Total	134	34.9	111	28.91	139	36.2	384	100

3.2 Demographic and socioeconomic characteristic of agroforestry adopters and non-adopters

Table 4 characterizes the demographic and socioeconomic factors that determine farmers' agroforestry adaptation to climate change and variability. It also statistically tests the significance of these factors using p-values.

The demographic and socioeconomic characteristics of agroforestry adopters and non-adopters in the Kochere, Wonago, and Yirgachefe districts reveal key factors influencing adoption decisions.

Age: Adoption is highest among the 51-60 age group (28.93%) and lowest in the 20-30 group (11.95%), likely due to greater experience and resources among older farmers. Non-adoption is highest in the 31-40 group (35.5%), reflecting challenges like economic pressures or lack of awareness. Age significantly influences adoption (chi-square = 0.001).

Gender: The majority of adopters (85.53%) and non-adopters (93.78%) are male, aligning with traditional roles in agriculture. Gender dynamics have a marginally significant impact (p = 0.05). Engaging women in agroforestry could boost adoption (Agarwal, 2010).

Family Size and Marital Status: Both factors show no significant impact on adoption decisions (p = 0.751 and p = 0.347, respectively), with similar distributions across adopters and non-adopters.

Education Level: Illiteracy is more prevalent among non-adopters (71.56%) than adopters (25.16%), with education significantly influencing adoption (chi-square = 0.02). Educational programs can enhance adoption among less educated populations (Mekonnen *et al*., 2020).

Farm Size: Larger farms (>1.6ha) are more common among adopters, while smaller farms (0-0.5 ha) dominate among non-adopters. Farm size strongly affects adoption (chi-square = 21.74, p < 0.001).

Access to Basic Services: Adopters (64.15%) report better service access compared to non-adopters (73.33% inadequate). Improved service access significantly supports adoption (chi-square = 4.01, p = 0.045).

Agroecology: Both groups predominantly reside in midland areas, with no significant differences in agro-ecological zones (p = 0.647).

Food Security Status: Non-adopters face higher food insecurity (74.67%) than adopters (25.16%). While food security correlates with adoption, it lacks statistical significance (p = 0.082).

Table 4. Demographic and socioeconomic characteristics of agroforestry adopters and non-adopters in South-eastern Ethiopia

Variables	Variable categories	Agroforestry adaptation decision							
		Adopters		Non-adopters		Total			
		Freq.	%	Freq.	%	Freq.	%	χ^2	p-value
Age	20-30	19	11.95	28	12.44		12.24	23.48	0.001
	31-40	33	20.75	80	35.50		29.02		
	41-50	35	22.01	78	34.67	114	29.87		
	51-60	46	28.93	37	16.44	83	21.61		
	I>60	26	16.35	2	0.89	28	7.29		
	Total	159	41.41	225	58.59	384	100		
Gender	Male	136	85.53	221	93.78	347	90.36	3.79	0.05
	Female	23	14.47	14	6.22	37	9.64		
	Total	159	41.41	225	58.59	384	100		
Family size	1-5	21	13.21	44	19.56	65	16.93	0.1	0.751
	6-10	56	35.22	67	29.78	123	32.03		
	>10	82	51.57	114	50.67	196	51.04		
	Total	159	41.41	225	58.59	384	100		
Marital status	Married	104	65.41	174	77.33	278	72.4	2.79	0.347
	Single	24	15.09	9	4.00	33	8.59		
	Divorced	12	7.55	14	6.22	26	6.77		
	Widowed	19	11.95	28	12.44	47	12.24		
	Total	159	41.41	225	58.59	384	100		
Education level	Illiterate	40	25.16	161	71.56	201	52.34	0.02	0.885
	Primary	58	36.48	46	20.44	104	27.08		
	Secondary	41	25.79	16	7.11	57	14.84		
	Certificate	20	12.58	2	0.89	22	5.73		
	Total	159	41.41	225	58.59	384	100		
Farm size, ha	0-0.5	40	25.16	170	75.56	210	54.69	21.74	<0.00
	0.51-1.6	41	25.79	41	18.22	82	21.35		
	> 1.6	78	49.06	14	6.22	92	23.96		
	Total	159	41.41	225	58.59	384	100		
Access to basic service	Inadequate	57	35.85	165	73.33	222	57.81	4.01	0.045
	Adequate	102	64.15	60	26.67	162	42.19		
	Total	159	41.41	225	58.59	384	100		
Agroecology	Mid land	128	80.50	161	71.56	289	75.26	0.21	0.647
	High land	31	19.50	64	28.44	95	24.74		
	Total	159	41.41	225	58.59	384	100		
Food security status	Insecure	40	25.16	168	74.67	208	54.17	3.02	0.082
	Secure	119	74.84	157	25.33	176	45.83		
	Total	159	41.41	225	58.59	384	100		
Participation in local institutions	Not participated	41	25.79	173	76.89	214	55.73	5.82	0.015
	Participated	118	74.21	52	23.11	170	44.27		
	Total	159	41.41	225	58.59	384	100		
Wealth and asset status	Poor	54	33.96	134	59.56	188	48.96	5.05	0.024
	Medium	76	47.00	75	33.3	151	39.32		
	Rich	29	18.40	16	7.11	45	11.72		
	Total	159	41.41	225	58.59	384	100		

Participation in Local Institutions: Adopters (74.21%) show greater engagement in local institutions than non-adopters (23.11%), significantly enhancing access to agroforestry resources (chi-square = 5.82, p = 0.015).

Wealth and Asset Status: Wealthier farmers are more likely to adopt agroforestry, with financial constraints limiting non-adopters (59.56%). Wealth significantly influences adoption (chi-square = 5.05, p = 0.024).

These insights highlight critical factors shaping agroforestry adoption and point to targeted interventions to support sustainable practices.

3.3 Descriptive Results of Outcome Variables: Climate Resilience Due to Farmers' Agroforestry Adaptation

In Table 5, climate resilience resulting from farmers' agroforestry adaptation is characterized and statistically analysed using t-tests and p-values to determine the level of significance.

Table 5. Summary of climate resilience due to farmer's agroforestry adaptation

Outcome variable	Variable categories	Agroforestry adaptation decision				Total		Statistical value	
		Adaptors		Non-adaptors					
		Freq	%	Freq	%	Freq	%	t-value	p-value
Climate resilience due to agroforestry adaptation	No	64	40.25	212	94.22	276	71.88	14.32	0
	Yes	95	59.75	13	5.78	108	28.13		
	Total	159	41.41	225	58.59	384	100		

The results presented in Table 5 provide a comprehensive overview of the relationship between agroforestry adaptation and climate resilience among farmers in the Kochere, Wonago, and Yirgachefe districts of the Gedeo Zone. The data reveals significant differences between agroforestry adopters and non-adopters, with implications for agricultural practices, policy-making, and community engagement.

3.4 Climate Resilience Outcomes Based on Adaptation Decision

Among agroforestry adopters, 59.75% (95 out of 159) report experiencing climate resilience due to their agroforestry practices. This indicates a strong positive perception of the benefits associated with agroforestry in enhancing their resilience to climate impacts.

In stark contrast, only 5.78% (13 out of 225) of non-adopters report experiencing similar benefits, with the overwhelming majority (94.22%) not perceiving any climate resilience from their agricultural practices.

The *t*-value of 14.32 and a p-value of 0.000 indicate a highly significant difference between the two groups regarding their experiences of climate resilience. This suggests that the adoption of agroforestry is strongly associated with improved climate resilience outcomes for farmers.

The stark contrast in climate resilience perceptions between adopters and non-adopters highlights the critical role that agroforestry can play in enhancing farmers' adaptive capacity to climate change. Agroforestry systems, which integrate trees with crops and/or livestock, provide multiple benefits, including improved soil health, increased biodiversity, and enhanced microclimates all of which contribute to greater resilience against climate variability (Nair, 2011).

3.5 Determinants for household's agroforestry based adaptation decision in response to climate change and variability

Binary logit was employed to identify significant factors determines household's agroforestry based adaptation decision and marginal effect after logit was employed to identify the extent to which the factors determines farmers adaptation in response to climate change and variability.

Table 6. Binary logit output of determinants of households decision to adoption of agroforestry to changing climate

Variables	Coef.	Std. Err	*z*	Effect	p-value
Age	0.772	0.160	4.80	0.181***	0.000
Sex	-0.925	0.521	-1.77	-0.226	0.076
Marital status	-0.178	0.214	-0.83	-0.041	0.405
Family size	0.173	0.216	0.80	0.040	0.423
Educational	0.034	0.304	0.11	0.007	0.911
Farm size	0.899	0.202	4.45	0.211***	0.000
Access to basic service	0.557	0.328	1.70	0.131	0.090
Access to market	0.503	0.445	1.13	0.117	0.259
Agroecology	0.074	0.390	0.19	0.017	0.848
Food security status	0.958	0.531	1.80	0.223	0.071
Income	0.500	0.354	1.41	0.115	0.158
Participation in institutions	1.130	0.451	2.51	0.264**	0.012
Wealth and asset	0.568	0.231	2.45	0.133**	0.014

Note: *** and ** indicates the variables are significant at 1% and 5% respectively

The results from the binary logit model presented in Table 6 provide valuable insights into the factors influencing households' decisions to adopt agroforestry practices in response to climate change in the Kochere, Wonago, and Yirgachefe districts of the Gedeo Zone. The coefficients (Coef.), standard errors (Std.Err), z-values, effect sizes, and p-values are critical for understanding these dynamics.

Age: The positive coefficient (0.772) indicates that as age increases, the likelihood of adopting agroforestry increases significantly (p-value: 0.000). Older farmers may possess more experience and knowledge about the benefits of agroforestry and are more willing to invest in long-term sustainable practices. The effect size (0.181) suggests that a one-unit increase in age is associated with an 18.1% increase in the probability of adoption. Older farmers often have deeper ties to their land and a greater understanding of environmental changes, as well as accumulated resources that facilitate initial investments (Mekonnen *et al*., 2020).

Sex: The negative coefficient (-0.925) suggests that being female is associated with a lower likelihood of adopting agroforestry, though this is marginally significant (p-value: 0.076). The effect size (-0.226) indicates that female-headed households are approximately 22.6% less likely to adopt agroforestry compared to male-headed households. Gender disparities in access to resources, education, and decision-making power can hinder women's adoption of agroforestry practices. Addressing these barriers through targeted interventions could enhance women's participation in sustainable agricultural practices (Agarwal, 2018).

Marital Status: The coefficient for marital status (-0.178) is negative but not statistically significant (p-value: 0.405). This suggests that marital status does not have a substantial impact on the decision to adopt agroforestry. Other factors may overshadow the influence of marital status, indicating that social structures or household dynamics might not play a critical role in agroforestry adoption in this context.

Family Size: The positive coefficient (0.173) indicates a slight increase in adoption likelihood with larger family sizes; however, this is not statistically significant (p-value: 0.423). Larger families may have more labor available for implementing agroforestry practices, but this factor alone does not significantly influence adoption decisions.

Educational Level: The coefficient (0.034) is positive but not significant (p-value: 0.911). This indicates that educational level does not significantly influence the decision to adopt agroforestry. This

finding may reflect a gap between formal education and practical agricultural knowledge, suggesting that hands-on training and local knowledge dissemination are crucial for promoting agroforestry (Zomer *et al*., 2016).

Farm Size: The significant positive coefficient (0.899) indicates that larger farm sizes are strongly associated with higher adoption rates of agroforestry practices (p-value: 0.000). An increase in farm size by one unit increases the probability of adoption by approximately 21.1%. Larger farms provide more opportunities for integrating trees into agricultural systems, allowing for diversified income sources and improved resilience against climate variability (Mastrorillo *et al*., 2016).

Access to Basic Services: The positive coefficient (0.557) suggests a potential link between access to basic services and agroforestry adoption, though it is marginally significant (p-value: 0.090). Access to essential services such as water, healthcare, and infrastructure can facilitate the adoption of agroforestry by improving farmers' overall livelihoods and reducing risks associated with climate change (Kiptot & Franzel, 2015).

Access to Market: The coefficient (0.503) indicates a positive relationship between market access and agroforestry adoption; however, this is not statistically significant (p-value: 0.259). Improved market access can enhance farmers' ability to sell agroforestry products, but additional factors may need to be considered to fully understand its impact (Singh *et al*., 2019).

Agro-ecology: The coefficient (0.074) is positive but not significant (p-value: 0.848), indicating that agro-ecological conditions do not significantly influence the decision to adopt agroforestry. This suggests that agro-ecological factors, while important, may not be the primary drivers of adoption decisions in this context.

Food Security Status: The positive coefficient (0.958) suggests that food security status is positively related to agroforestry adoption, approaching significance (p-value: 0.071). Households experiencing food insecurity may be less likely to invest in long-term practices like agroforestry due to immediate survival concerns (Mekonnen *et al*., 2020).

Income: The positive coefficient (0.500) indicates a potential relationship between income and agroforestry adoption; however, it is not statistically significant (p-value: 0.158). Higher income could provide farmers with the resources needed for investment in agroforestry practices, but other barriers might limit this relationship (Zomer *et al*., 2016).

Participation in Institutions: The significant positive coefficient (1.130) indicates that participation in institutions is strongly associated with higher adoption rates of agroforestry (p-value: 0.012). An increase in institutional participation raises the probability of adoption by approximately 26.4%. Engagement with agricultural institutions can provide farmers with valuable resources, training, and support networks essential for successful agroforestry implementation (Kiptot & Franzel, 2015).

Wealth and Asset Ownership: The positive coefficient (0.568) indicates a significant association between wealth/assets and the likelihood of adopting agroforestry practices (p-value: 0.014). Higher asset ownership increases the probability of adoption by approximately 13.3%. Wealthier households may have greater access to resources necessary for implementing agroforestry systems, thereby enhancing their adaptive capacity to climate change (Mastrorillo *et al*., 2016).

3.6 Impact of participating in agroforestry adaptation on climate resilience

To identify the significant impact of participating in agroforestry adaptation on climate resilience, the researchers employed the propensity score matching model. The output of this model is explained in Table 7.

The results presented in Table 7 illustrate the Average Treatment Effect on the Treated (ATT) for climate resilience due to participation in agroforestry among households in the Kochere, Wonago, and Yirgachefe districts of the Gedeo Zone. The data reveals significant differences in climate resilience between agroforestry adopters and non-adopters.

Table 7. Average Treatment Effect on the Treated (ATT) for Climate Resilience Resulting from Participating in Agroforestry

Outcome variable	Sample	Treated	Control	Difference	T-stat	P-value
Climate resilience	ATT	1.1949	0.1155	-1.079	14.32	0.000

The outcome variable, climate resilience, shows an ATT value of 1.1949 (Treated) versus 0.1155 (Control), with a difference of -1.079. This indicates that agroforestry adopters have a substantially higher level of climate resilience compared to the control group (non-adopters). The T-statistic of 14.32 and a p-value of 0.000 confirm that this difference is statistically significant, providing strong evidence that participation in agroforestry enhances climate resilience.

4 Discussions

The adaptation status of farmers to agroforestry practices in Kochere, Wonago, and Yirgachefe districts of the Gedeo Zone reveals notable variation. In Kochere, 65.67% (88 farmers) did not adopt agroforestry, while 34.33% (46 farmers) did. Similarly in Wonago, 62.16% (69 farmers) reported non-adoption, with 37.84% (42 farmers) adopting agroforestry. In contrast, Yirgachefe recorded higher adoption rate of 51.08% (71 farmers), with 48.92% (68 farmers) not adopting. This relatively higher adoption in Yirgachefe may reflect favorable conditions of community engagement and institutional support. Smallholder farmers in the study area perceive climate change as an immediate threat to agricultural productivity (Zomer *et al*., 2016). They report observable shifts in weather patterns, including altered rainfall distribution, rising temperatures, and unpredictability (Mastrorillo *et al*., 2016). These climatic changes adversely affect crop yields, water availability, and overall agricultural output (Zomer *et al*., 2016). Key informants emphasized the challenges posed by erratic weather, such as frequent droughts and irregular rainfall which contribute to crop failures and food insecurity. Farmers struggle to plan effectively due to weather uncertainty (Mastrorillo *et al*., 2016), and water scarcity and heat stress further affect vulnerable crops like coffee, maize, and beans (Nair, 2011; Zomer *et al*., 2016).

To enhance resilience and reduce dependence on monoculture systems, farmers diversify their crop selection (Mastrorillo *et al*., 2016). Agroforestry practices are widely implemented to improve soil health, enhance biodiversity, and generate supplementary income (Zomer *et al*., 2016). These systems contribute to soil conservation, erosion control, and the maintenance of soil fertility (Nair, 2011). In response to water scarcity, farmers adopt water harvesting techniques as a key adaptation measure (Mastrorillo *et al*., 2016). Participants in local networks and extension services further facilitate the adoption climate smart practices (Nair, 2011; Zomer *et al*., 2016). The multifunctional benefits of improved soil quality, increased biodiversity, and enhanced water retention support climate resilience and buffer households against climate induced shocks.

The study finds that the age of the household head positively influences farmers' decision of adopting agroforestry. Older farmers tend to adopt more readily due accumulated agricultural experience and greater capacity to assess the benefits of new technology (Gebre, 2015; Gbetibouo, 2009; Maddison, 2006; Ndambiri, 2012; Nhemachena, 2007). This trend is consistence with findings from Ethiopia and other regions (World Bank, 2008).

Farm size positively correlates with adaptation options. Large landholdings allow for crop diversification, dry season-production, and integration of livestock with diverse cropping systems (Abrham, 2017; Hassan *et al*., 2020; Megersa; 2022; Misganaw *et al*., 2014). However, some studies suggest that farmers with extensive cultivated land may be more risk-averse and less inclined to adopt new practices (Amare; 2017). Drawing from theories of agricultural intensification and risk aversion, larger farms may offer greater flexibility for agroforestry implementation, though decisions remain influenced by individual perceptions, resource availability, and economic consideration (Hassan *et al*., 2020; Mekonen *et al*., 2022).

Participation in local institutions significantly influences adaptation decisions. Institutions whether governmental or civic, political, or private, play a vital role in promoting adaption strategies and fostering

community level responses to climate change (Adger, 2008; Amare, 2017; Belay, 2017; Bekele, 2020). Environmental factors Soil fertility, topography, and water availability also shape adaptation choices (Fissha *et al*., 2019). Understanding local ecological conditions is essential for designing effective strategies that support soil conservation, biodiversity, and microclimate regulation. Supportive policies, including government subsidies, insurance schemes, and extension services, further influence farmers' adaptation decisions (Obayehu, 2014).

The household's wealth status is another determinant of adaptation. Wealthier households are better positioned to invest in agroforestry due to greater access to finance and resources (Obayehu, 2014). In central Kenya, adopters of climate adaptation strategies report higher incomes than non-adopters (Asayehegn, 2017). Increased farm income resulting from adaptation enhances household well-being, especially in Ethiopian, where crop income constitutes a major a major share of household earnings (Fissha *et al*., 2019). These findings underscore the importance of improving household wealth and asset ownership to strengthen adaptation capacity.

Focus group discussions provided rich qualitative insights into the determinants of agroforestry adoption among smallholder farmers in the Gedeo Zone. Perspectives either farmer groups highlighted the influence of socio-economic dynamics, environmental conditions, resource access, policy framework, market forces, and cultural practices. These discussions revealed the complex interplay of factors shaping adaptation decisions and emphasized the need for context-specific interventions.

5 Conclusion

The study reveals that agroforestry adoption in the Gedeo Zone is shaped by a complex interplay of social, economic, and institutional factors. These dynamics highlight the importance of tailored strategies that address local barriers while leveraging existing strengths. Promoting agroforestry requires more than technical solutions it demands inclusive policies that consider age, gender, education, and access to resources. The demonstrated link between agroforestry and climate resilience reinforces its role as a cornerstone of sustainable rural development. To unlock its potential, coordinated efforts among policymakers, community leader, and development partners are essential. Such efforts can foster equitable participation, strengthen adaptive capacity, and ensure long-term food and livelihood security across the region.

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Competing interest

The authors declare that there are no conflicts of interest related to this manuscript.

Authors contributions

Tigistu Gezahegn contributed to the conceptualization, data collection, formal analysis, investigation, project administration, visualization, and overall original manuscript writing. Mesele Negash played a key role in designing the methodology, supervising, validating, and reviewing the manuscript with constructive comments. Eshetu Yirsaw made significant contributions by reviewing, supervising, validating, and providing comments on the manuscript.

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