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Abstract

The pastoral and agro-pastoral communities in South Omo Zone of Ethiopia are highly vulnerable to climate change impacts such as droughts and floods. To deal with this challenge, they have applied various climate change adaptation strategies (CCAS) including rangeland management, livelihood diversification, and herd mobility, to strengthen and improve their resilience, dietary diversity, and food consumption. To look into these problems, a multi-stage sample technique was used, and semi-structured questionnaires were used to gather information from 325 homes in three districts. The study used descriptive statistics and a multinomial endogenous switching regression (MESR) model to correct for selection bias. Descriptive statistics result indicated combined adaptation strategies, or full strategies, were the most prevalent at 35.38%; only 5.54% of households adopted none of the measures. The results of the MESR model showed that, in all adoption categories, climate adaptation techniques greatly increased household food consumption and dietary diversification. Estimates of the average treatment effect on the treated (ATT) revealed that households adopting multiple or full sets of climate adaptation practices achieved mean improvements of 8.45 in HDDS and 44.80 in FCS compared to non-adopters. Furthermore, the average treatment impact on the untreated (ATU) suggested that non-adopters' family dietary diversity and food consumption scores may have considerably improved if they had used these strategies. Consequently, it is recommended that policymakers and stakeholders increase support for pastoral and agro-pastoral adaptation strategies and integrate these strategies into development plans to improve household dietary diversity, food consumption score, and climate resilience in the study area.

Keywords: ***Adaptation strategies, ESRM, HDDS, FCS, pastoral and agropastoral, South*** **omo**

1. Introduction

Climate change is a major global issue today. It impacts all countries and areas, but the effects vary based on local circumstances(R de Bandtetal, 2023). Climate change adversely affects human systems, water security, and food production. It is recognized as a significant challenge to sustainable development due to its potential to exacerbate catastrophic extreme events (Kikstra et al., 2022). The evidence indicates that the observed changes in extreme weather events, such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and their impacts on human livelihoods, have intensified across all regions of the world(Shukla et al., 2023). Climate variability and extreme

weather are drivers of the increasing global hunger crisis., negatively affecting all four dimensions of food security: availability, access, utilization, and stability (Saint Ville, Po, Sen, Bui, & Melgar-Quiñonez, 2019).

Climate unpredictability exacerbates existing economic problems in Sub-Saharan Africa (SSA), where an estimated 239 million people experience food insecurity and 70% of the region's poorest individuals subsist on less than $1.25 per day(Sawadogo, Matsumura, Esham, & Fernandez, 2025) underscoringthe necessity of agricultural development as a strategy for reducing ppoverty, basedon (FAO, 2026) Agriculture in Ethiopia accounts for 34.6% of the GDP, serving as a major source of livelihood for 80% of the population and generating 90% of export revenue. The livestock population is an integral part of agriculture; Ethiopia has the largest livestock population in Africa, the sector contributes approximately 40% of Ethiopia’s agricultural GDP, 20% of the country’s overall GDP, and 20% of total foreign exchange earnings(Beyene, 2025).

More than 12 million Ethiopians depend on pastoralism and agro-pastoralism, which constitute 12–16 percent of GDP and 30–35 percent of agricultural GDP in Ethiopia (FDRE CSA, 2013) (2012). Pastoralists and agro-pastoralists in Ethiopia inhabit approximately 63% of the country's landmass. They raise an estimated 42% of the country's cattle, 7% of its goats, 25% of its sheep, 20% of its horses, and all of its camels(Duguma, Gobena, & Beyene, 2026) Livestock (about 23% of national cattle population, 62% of total goat population, 50% of sheep and 100% of all camels) play a vital role in these areas. Livestock production in Ethiopia's pastoral areas provides an important source of income. Agro-pastoralism on the other hand has little crop production and livestock dominate(Duguma et al., 2026); (Sintayehu et al., 2025).

Recurrent droughts and floods significantly affect pastoralists and agro-pastoralists, leading to the loss of 50–80% of their cattle herds through declining feed and water availability, increased livestock diseases, and deterioration of grazing lands(Birhanu & Destaw, 2026). Consequently, climate change continues to constrain rural incomes, weaken livelihood resilience, and exacerbate food insecurity across the country(Duguma et al., 2026).

South Omo in southern Ethiopia faces similar difficulties as a result of the Omo River's seasonal floods. These floods contribute to disease, drought, and food insecurity. The October-December rains in 2024 are forecast to be below average due to La Niña conditions. Previous heavy rains have also damaged crops, so communities such as Dassenech and Bena-Tsemay face a high risk of losing livestock and crops, which leads to nutritional problems. Insufficient feed is available, so livestock become weak and susceptible to disease(Seid, 2025). (Gole, Kuris, & Gemeda, 2026); (Desalegn & Mulu, 2021).

Ethiopia is one of the world's most impoverished countries. It is also an ecologically fragile country whose population is rapidly increasing. This population is heavily affected by climatic events since Ethiopia's economy is primarily agricultural(Bouteska *et al.*, 2024);(FAO, 2014) & (Dessie, Belete, & Dagnew, 2024);(Unicef, 2018). To address the impacts of climate change, governments and development organizations have promoted adaptive farming techniques at the local level(Zegeye, Tegegne, & Bedemo, 2026). Climate adaptation strategies refer to the methods by which farmers respond to current or anticipated climate impacts, with the goal of reducing damage or exploiting potential benefits (Zegeye et al., 2026).

Pastoral and agro-pastoral communities in the South Omo Zone use various strategies to mitigate and cope with climate change impacts. These include approaches based on their experience and knowledge, as well as government-led initiatives, such as small-scale irrigation and the expansion of diverse income-generating activities. In addition, some communities make use of customary institutions to offer early alerts about impending natural calamities. Herd maximization to mitigate risk, species diversification, herd splitting, and herd mobility to areas where water and fodder are available; harvesting of wild fruit; and mutual help and stock transfer are practiced. Rangeland-related strategies, such as traditional enclosures for calves and soil and water conservation inside area closures, were major strategies employed to mitigate the unpredictable impacts of climate change and to reduce food insecurity(Seid, 2025).

Despite these efforts, empirical studies on the impact of these strategies on pastoral and agropastoral households' dietary diversity and food consumption remain scarce in South Omo, Ethiopia. Nonetheless, available studies suggest that the adoption of these practices may enhance Household Dietary Diversity Scores (HDDS) and Food Consumption Scores (FCS)(Zegeye et al., 2026) The food security framework views food as a commodity, while the nutrition framework focuses on human well-being. To improve household nutrition, it is crucial to enhance food security by increasing access to a variety of foods. Therefore, adoption and adaptation strategies not only for the severity of climate change impacts but also the enhancement of income levels and food security(Degfachew, Dilnesaw, & Massa, 2025b; Deressa, Hassan, & Ringler, 2011),(Begashaw et al., 2024).;(Mwakaje et al., 2024).(Hutjis, 2015);(Ali and Erenstein, 2017);(Gebre *et al.*, 2023);(Grigorievaetal., 2023). Therefore, it is crucial to adopt climate change adaptation strategies that consider their advantages.

Empirical studies in Ethiopia have often focused on a single adaptation measure when examining the impact of climate change adaptation strategies on food security and farm income (Admasu, Haji, Siyum, & Ndemo, 2024a; Gizaw, Demissie, & Dilie, 2025; Zegeye et al., 2026),(Amare & Simane, 2018), Evaluating single strategies in isolation may be insufficient because it overlooks the joint impacts of complementary adaptation measures as well as unobservable heterogeneity across households. To address this limitation, subsequent studies have applied the endogenous switching regression model to capture unobserved heterogeneity in food security and adaptation. (Admasu et al., 2024a; Zegeye et al., 2026), including research on farm income in Burkina Faso and Southwest Ethiopia(Sawadogo et al., 2025).

Studies(Admasu, Haji, Siyum, & Ndemo, 2024b);(Ali, Menza, Hagos, & Haileslassie, 2023) revealed that farmers who adopted climate-smart agriculture would have had significantly lower daily calorie intake if they had not adopted it, and non-adopter farmers would have gained significantly higher daily calorie intake if they had adopted it. Households adopt climate-smart agriculture (CSA) to ensure food security, and sampled households adopted at least one CSA practice, and CSA adopters generally exhibit higher household dietary diversity scores than non-adopters, and all CSA practices have a positive and significant effect on the pattern of welfare improvement among smallholder farmers, but combinations of CSA practices provide the highest payoffs.

However, most existing studies have largely centered on climate-smart agriculture and isolated, single-track strategies. This has left a critical gap in empirical evidence particularly regarding the real-world adaptation practices employed by pastoral and agro-pastoral households in the South Omo region to achieve meaningful nutrition security outcomes.

In order to address this gap, the current study used nutrition sensitive indicators (Food Consumption Score-FCS and Household Dietary Diversity Score-HDDS) to assess climate variability and nutritional status. Specific focus was on assessing how well household level adaptation strategies such as rangeland management, livelihood diversification and mobility were at addressing climate variability. This study showed that while individual adaptation strategies did not appear to have an impact, combined adaptation strategies greatly improved dietary intake and diversity. This study provides vital practical information on how human wellbeing can be protected in pastoral and agropastoral areas within some of the most vulnerable dryland systems globally.

1.2 .Conceptual framework

Climate change is regarded as a significant global threat to both peaceful business frameworks and food security.(Darge, Haji, Beyene, & Ketema, 2023) making climate adjustment techniques (CCAS) fundamental for maintaining animal generation and improving strength(Zakari, Ibro, Moussa, & Abdoulaye, 2022). This thought created a conceptual framework connecting CCAS with the household dietary differences score and nourishment utilization score (Fig. 1). Within the system, pastoralists and agro-pastoralists who embrace certain adjustments improve on their farms, such as livelihood diversification, range land management, herd mobility, and SWC measures, and can improve livelihood systems, subsequently improving household dietary diversity scores and food consumption scores beneath changing climate.

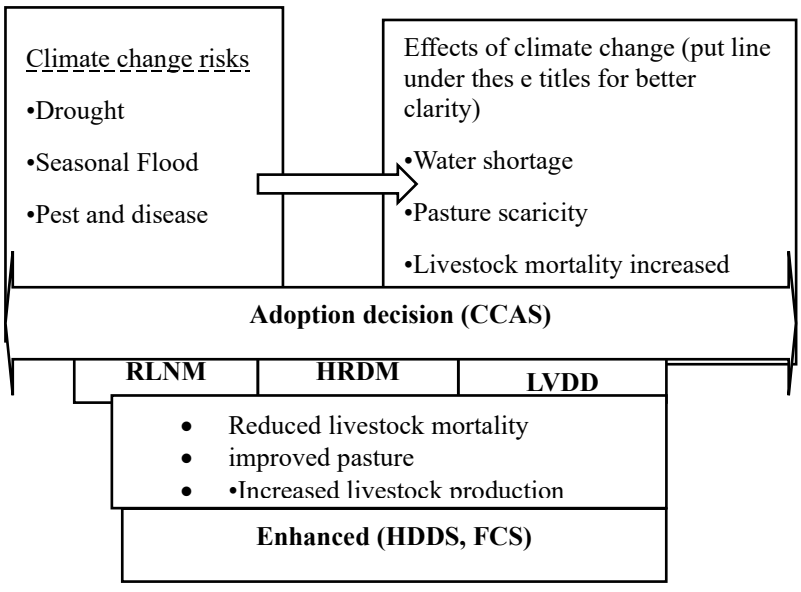

Figure 1Conceptual framework

3. Research Methodology

2.1. Study area Description

South Omo Zone is located in Ethiopia's southern region, 812 km southwest of the capital, Addis Ababa. There are two city administrations, six districts, and 172 rural and 17 urban kebeles.Out of 32 groups, 15 multiethnic groups are found in the South Omo Zone; these groups have their own geography, language, culture, and social identity. It covers a total area of 23,535 km². Geographically, it is situated between 5°0◦0′′N and 36°0◦0′′E' longitude. Its elevation ranges from 272 to 3,500 m.a.s.l.and it is situated between 5°0◦0′′N and 36°0◦0′′E' longitude.The area is arid and semi-arid, with some pockets of sub-humid zones(Abebe et al., 2025). It is bordered by: Ari zone to the north, Konta in southwest Ethiopia, the Gofa and Besketo zone in the northeast, Ale and Konso zone in the east, Kenya to the south, the Oromia region (Borena zone) in the southeast and southwest, and South Sudan in the west and northwest directions

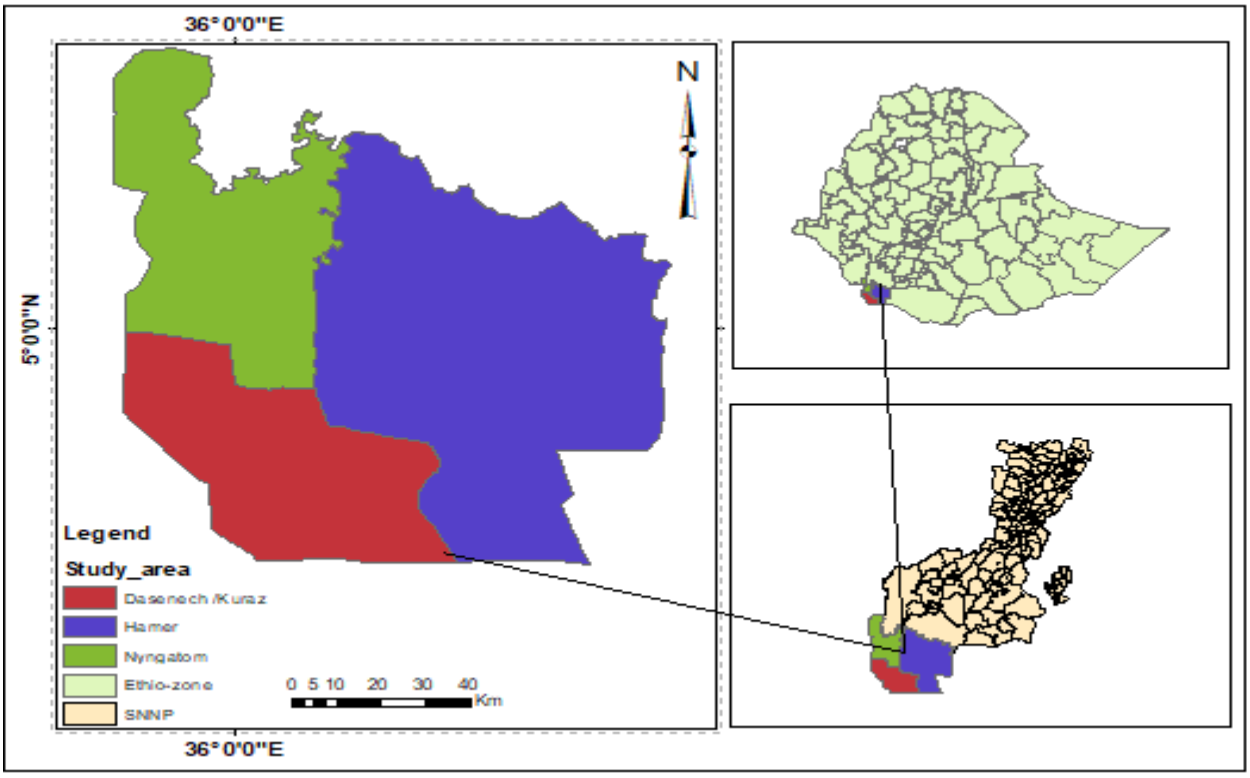

Figure 2Study area map

evidence, (CSA, 2007) The total population of South Omo was 573,435 persons with 286,607 males and 286,828 females. It covers an area of 21,055.92 square kilometers and has a population density of 27.23 people per square kilometer. ...43,203 (7.53%) of the total population lived in urban area, while 25,518(4.45%) people were pastoralists. Hammer, Dasenech and Nyangatom Woredas have a total population of 252,109 male 131,288 (52%)

and female 120,821 (48%), these three woredas have a combined landmass of 10,449.19 km², covering a significant portion of the South Omo zone which are administratively divided into 93 rural and 5 urban kebeles. The zone features diverse agroecological zones ranging from hot and arid to humid tropical environments. Each agro-ecological zone constitutes the following percentage of the total area of the zone. Weyna Dega is 5.6%, Semi-Kola is 60%, and Kola is 34.4%; the annual mean temprature ranges from 26°C to 40°C, and the mean annual rainfall is between 350mm to 503mm. The zone has a bimodal rainfall system where the long rainy season is from mid-February to May and the short rainy season from October to December (Abebe et al., 2025).

Livestock farming is the main livelihood of pastoralists and semi-pastoralists. For example, while cows are used only for milk, they also use bulls for sale and for traditional marriages; sheep and goats are also used for market; meat and milk are used for food; accordingly, this zone is a potential source of livestock resources. For example, large numbers of cattle, 4,757,960, are found in the area, including sheep (2,484,370), goats (2,005,632), chickens (52,179), donkeys (355,353), and so on. The second type of livelihood is crop farming, such as sorghum, maize, haricot bean, banana, and moringa. The pastoralists living in the Omo River area of Dasenech and Nyangatom woredas use the Omo River for sorghum and livestock farming, using irrigation. In addition, those living near the city engage in activities such as selling firewood and cattle trading; those living in the Omo area also engage in fish farming(Gebeyehu, Snelder, Sonneveld, & Abbink, 2021).

2.2. Research Design

This study employed a mixed-methods research approach using a cross-sectional research design(Hasan & Kumar, 2024). Quantitative data were collected through a household survey and analysed using numerical data. While a qualitative approach, which collected through interviews (KIIs), focus group discussions (FGDs), and field observations, was used to complement the quantitative findings

2.4 Sampling techniques and sample size Determination

Multistage sampling techniques were employed, such as purposive, stratified, and simple random sampling methods, to select the study districts, kebeles, and household respondents.

In the first stage, three districts, Hammer, Dasenech, and Nyangatom, were purposively selected from the six pastoral and agropastoral districts of the South Omo Zone by considering their vulnerability of livelihood systems to climate change, flood, drought, and long food insecurity.

In the second stage, kebeles were stratified according to their predominant livelihood practices, which primarily depended on livestock herding or were pastoral and which integrated crops and livestock (were agropastoral). This was made with the help of the collaboration of the districts' agricultural and natural resources offices' heads and experts.

Subsequently, six kebeles were randomly selected from the identified strata to ensure adequate representation of both livelihood categories. The selected kebeles included Shankokelma (agro-pastoral) and Genebal (pastoral) from Hamer District; Bandira and Lovet (both pastoral) from Dassanech District; and Napusmuria (agro-pastoral) and Lokoper (pastoral) from Nyangatom District. The sample size from each kebele was determined based on proportion to the total human population in each selected kebele. The numbers of households in each sampled kebele were 1285 households in agro-pastoral and 1011 households in pastoral areas. Thus, a total of 325 household respondents were chosen using random sampling methods. The required sample size was determined based on the sample size from each kebele, which was determined based on proportion to the total human population in each selected kebele. The numbers of households in each sampled kebele were 1285 households in agro-pastoral and 1011 households in pastoral areas. Thus, a total of 325 household respondents were chosen using random sampling methods. The required sample size was determined based on the(Kothari, 2004) formula, a commonly used formula in different social research. The level of precision, confidence level, and degree of variability are considered(Singh & Masuku, 2014).

$$n=\frac{Npqz^2}{e^2(N-1)+pqz^2} = \frac{2296*0.5*0.5*(1.96)^2}{0.05^2(2296-1)+(0.5*0.5)*(1.96)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

n = 324.06 (≈ 325 agro pastoral household)

Where n is the sample size for the study, N is the total population of the sample kebeles, Z is the selected critical value of the desired confidence level (95%), p is the estimated proportion of an attribute that is present in the population (0.5), q = 1 - p, and e is the desired level of precision, which is assigned a value of 5% (0.05).

2.5. Methods of Data Collection

A household survey was conducted among 325 pastoral and agro-pastoral households to collect data on demographic and socio-economic characteristics, climate adaptation coping mechanisms (e.g., seasonal mobility, herd splitting, livestock destocking, area closure, soil and water conservation, rotational grazing, and migration to other places), and their effectiveness in enhancing food diet diversity.

Food items consumed in the last 24 hours number of food items consumed within 24 hours questionnaires were developed through KoboToolbox and translated into Amharic, Hagering, Dasenech, and Nyangatom and was pretested before use in the field.

Eight trained local enumerators with relevant experience conducted the interviews using KoboCollect between December 2025 and February 2026.

A total of 32 key informants were purposively selected from zonal, district, and kebele levels based on their expertise and experience. Participants included agricultural, livestock, natural resource, climate change, and environmental experts, as well as development agents and pastoral/agro-pastoral elders. 6 FGDs (FGDs consisted of 6-12 participants each in the selected kebele s) were conducted. These discussions were led in local languages, lasted 45-50 minutes. Participants represented men, women, youth, and elders with knowledge of local livelihoods,

culture, and indigenous practices. The qualitative data were recorded by note taking and recordings during discussions and were complemented by field notes and photographs.

2.6. Method of Data Analysis

Both descriptive and econometric analyses were used to achieve the study objectives. Descriptive analysis was performed using frequencies and percentages to analyse household characteristics and the level of adaptation to improve and diversify the food diet. Qualitative data, collected from FGD and KII content, and theme analysis were used to assess data.

2.6.1. Measurement of Variables

Outcome variable

Household dietary diversity score (HDDS

Household Dietary Diversity Score (HDDS) is a consumption indicator that directly captures the core of diets consumed over the last 24 hours as reported by the households. HDDS are created by adding up the number of different foods or food groups that were consumed during the reference period, which is often 24 hours. We can classify households as low dietary diversity (DD) (≤ i3), medium DD (4 ≤ iDD ≤ i6), and high DD (≥ i7). HDDS will be used to analyze the food security status of the sample households. According to(Saint Ville et al., 2019) (Huluka & Wondimagegnhu, 2019)The food was divided into 12 groups.

Table 1Household dietary diversity score (HDDS

Food groups	Number
Any bread, rice, or any other foods made from millet, sorghum, maize, wheat, or any other locally available grain	A
Any potatoes, yams, cassava, or any other foods made from roots or tubers	B
Any vegetables	C
Any fruit	D
Any beef, pork, lamb, rabbit, or other mammals, chicken, duck, other birds, and organ meats	E
Any eggs	F
Any fresh or dried fish, or shellfis	G
Any foods made from beans, peas, and lentil	H
Any milk, or milk product	I
Any food made with oil, fat, or butter (including animal fat)	J
Any sugar	K
. Any food, such as coffee or tea	L

Note: iftheanswerwasyes, awarded 1point, and if the answer wasno, awarded 0 point. Source: Adapted from (Swindale, A.; Bilinsky, P. 2006).

$$\text{HDDS} = \sum_{i=1}^{12} \text{Di} \qquad (2)$$

Food consumption score (FCS)

The Food Consumption Score (FCS) indicator is a composite score based on households' dietary diversity, food consumption frequency, and relative nutritional value of different food groups. The FCS aggregates household-level food consumption data in terms of frequency over the previous seven days and weights the data according to the relative nutritional value of the consumed food groups. The FCS is a proxy indicator of households' food intake or caloric consumption. The household is because of this categorized into three groups based on the FCS Poor Food Consumption Score (FCS 0-21) Borderline Food Consumption Score (FCS 21. 5-35) Acceptable Food Consumption Score (FCS 35. 5-112) a high FCS score can be used to suggest that the household has a sufficient amount of food consumption. The lower the FCS score indicates that the household does not have enough food intakes. The FCS is a good proxy for the current food security status and is highly correlated with other food security proxy indicators, including HDDS5, rCSI, and FCS-N (vitamin A, protein-rich, and hem iron intake).

Table 2 Food consumption score (FCS)

Food groups	Frequency of consumption(with 7days)	Weight	Frequency x weight
Cereals, grains, roots, and tubers		2	
Legumes/pulses, nuts, and seeds		3	
Milk and other dairy products		4	
Meat, fish, and eggs		4	
Vegetables and leaves		1	
Fruits		1	
Oil/fat/butter		0.5	
Sugar or sweets		0.5	
Condiments		0	

Note: Poor (0-21), Borderline (21.5-35) and Acceptable (35.5-112). Source; Food Consumption Score Guidance, 2024

$$\text{FCS} = (7 \times 2) + (2 \times 3) + (3 \times 4) + (2 \times 4) + (2 \times 1) + (1 \times 1) + (7 \times 0.5) + (7 \times 0.5) \text{ FCS}$$
$$= 14 + 6 + 12 + 8 + 2 + 1 + 3.5 + 3.5 = 50 \qquad (3)$$

Among various indicators of nutritional security, the Household Dietary Diversity Score (HDDS) and the Food Consumption Score (FCS) were used as nutritional outcome indicators for this study to evaluate the impact of climate change adaptation strategies(Degfachew et al., 2025b).

Household Dietary Diversity Score (HDDS) is a qualitative methodology that has been validated in different countries as an approximate measure of food availability and food accessibility aspects of food security. The nutrition security level of the household will be the lowest level of nutrition security if the household falls in the range of the lowest dietary diversity score; medium level of nutrition security if the household falls in the range of the medium dietary diversity, and the highest level of nutrition security if the household falls in the range of the highest dietary diversity score (Degfachew et al., 2025b).

An increase in dietary diversity is associated with socioeconomic status and household food security. We have used HDDS less than or equal to three as a low dietary diversity group, between four and six as a medium category, and greater than or equal to seven as a high diversity score category. Household Dietary Diversity Score (HDDS) has been validated in different countries as an approximate measure of food availability and food accessibility aspects of food security(Wiesmann, Bassett, Benson, & Hoddinott, 2009). An increase in dietary diversity is associated with socioeconomic status and household food security. We have used HDDS less than or equal to three as a low dietary diversity group, between four and six as a medium category, and greater than or equal to seven as a high diversity score category(Wiesmann et al., 2009).

Climate change adaptation strategies (treatment variables)

Utilizing qualitative insights from interviews with key informants, focus group discussions (FGDs), and household survey data, three adaptation strategies were selected as the primary treatment variables for this research.A household was classified as a climate change adaptation strategy (CCAS) adopter (1) if it had adopted at least one of these three practices; otherwise, it was classified as a non-adopter (0). Accordingly, herd mobility, livelihood diversification, and rangeland management were chosen as the treatment variables to estimate the outcome variables (HDDS and FCS).

The term 'livestock mobility' is widely utilized in literature regarding pastoralism, though it frequently remains undefined. In practice, livestock mobility is an important strategy used by pastoralists to maintain ecological and socio-economic balance. The strategy is to move herds to areas with better grazing conditions to ensure access to essential resources during the dry season and times of crisis(Turner & Schlecht, 2019). In practice, livestock mobility is an important strategy used by pastoralists to maintain ecological and socio-economic balance.

Livelihood diversification is a process where pastoral households participate in a range of economic activities to improve income stability and reduce vulnerability.This diversification is a strategy to respond to economic uncertainty, environmental issues, and social transformations that are underway. Households with diversified livelihoods differ from subsistence pastoralists who depend on livestock production in that they combine livestock and non-farming activities to maximize sources of income and improve overall resilience (frankellies, 1998).

Rangeland management refers to the practices and strategies implemented to maintain or improve the health and productivity of rangelands, addressing factors such as grazing pressure, soil stability, and vegetation health to prevent degradation and enhance ecosystem services. effective management consider ecological and socio-economic factors to respond to issues such as climate change and conflicting land uses(Daba & Mammo, 2024).Households that employ CCA strategies show a statistically significant increase in HDDS and FCS than those that don't use such strategies.

Explanatory variables were selected based on a review of relevant literature. These include the demographic characteristics of the household head, such as age, sex, level of education, and size of the family.Farm size, plot distance, Tropical Livestock Units (TLU), and wealth status are used to capture asset and production endowments. Institutional and market access factors include access to information, market distance, access to credit services,

extension contacts, social group membership, and participation in the Productive Safety Net Programme (PSNP)(Kpadonou, Owiyo et al., 2017).

Table 3Summary of variables

variables	Descriptions	
Out come variables	**Household Dietary Diversity Score (HDDS)**	continuous
	Food consumption score(FCS)	continuous
Treatment variables Climate change adaptation strategies(CCAS)	(1) If it had adopted at least one of these three practices. Otherwise, it was classified as a non-adopter (0).	Dummy
If Adopter (LVDD,HRDM,RLNM)	Livelihood diversification(LVDD)	dummy
	Herd mobility(HRDM)	dummy
	Rangeland Management (RLNM)	dummy
Independent variables		Expected sign
Sex of household head(SHH)	Dummy (male/female)	+
Age of the household head(AGE)	Continous(year)	-/+
Education level(EDU)	Continous in Grade	+
Household family size(FMS)	Continous ADE	+
land size (LDS)	Continous hectare	+
Livestock ownership(LH)	Continuous (TLU)	+
wealth status(WSHH)	Poor/rich	+
Access to climate change information(ENFO)	Dummy (yes/no)	+
Frequency of extension contact(EC)	Continous	+
Distance to plot (DSP)	continuous	+
credit service(CA)	Dummy (yes/no)	+
Market Distance(MKD)	Continous	+
Productive Safety Net Programme (PSNP)	Dummy (yes/no)	+
Social group participation(SGPP)	Dummy(ye/no)	+

2.6.2. Exclusion variables in the MESR model

The validity of the MESR model requires at least one instrumental variable of farmers' adoption decisions without directly affecting outcome indicators(Adego, Simane, & Woldie, 2019). Following the approach of (Degfachew, Dilnesaw, & Massa, 2025a) This study uses climate information and participation in the PSNP to address potential endogeneity. These variables serve as exclusion restrictions that influence the adoption of climate adaptation strategies among pastoral and agro-pastoral households, while having no direct impact on dietary diversity or food consumption scores. Incorporating such instruments strengthens identification, enhances robustness, and provides deeper insight into adoption dynamics. Valid instruments must meet relevance and exogeneity conditions(Zegeye et al., 2026). Based on these criteria, the researchers argue that climate information and participation in the PSNP were selected as instrumental variables in this study. We execute the optimized selection model with exclusion

restrictions, adding 'force' to prevent Stata from crashing in cases where a random bootstrap draw lacks certain regime variations.

3.4.2 Multinomial endogenous switching regression (MESR)

To evaluate the impact of climate adaptation strategies, this study utilizes the endogenous switching regression (ESR) model. Originally formulated by (Lee, 1982). This method is widely used in contemporary impact evaluations to extend the selection framework of Heckman(Ojo & Baiyegunhi, 2021). The ESR framework has three methodological advantages: (i) it accounts for selection bias due to unobservable characteristics; (ii) it provides efficient and consistent estimates of the parameters through proper adjustments in the outcome equations; and (iii) it allows us to assess the effects of isolated and combined agricultural methods(Zegeye et al., 2026). We apply this model assuming that pastoral and agropastoral households decide whether or not to adopt climate adaptation measures. In a random utility framework like in(Toiba, Hartono, Retnoningsih, & Rahman, 2021). Households choose adaptation if the expected utility from adaptation is greater than from non-adaptation. The analytical procedure consists of two distinct steps. The first stage is a selection equation based on a latent variable, Di*, that captures the expected net benefits of undertaking adaptation strategies:

$$(Di *= Xi\alpha \ + ui \ where \ Di = 1 \ if Di *> 0, and 0 otherwise \ (1)$$

Where D_i is a binary dummy variable which takes the value of one if a household undertakes an adaptation strategy (any level of adaptation strategy including 1-, partial, multi-, or full adaptation), and zero otherwise. X_i is a vector of variables that determines a household's adaptation strategies, α are the parameters to be estimated, and u_i represents the error term.

The second stage specifies the outcome equations that are used to assess the effect of climate adaptation strategies on the Household Dietary Diversity Score (HDDS) and Food Consumption Score (FCS)(Baylie & Pércsi, 2025). The model will distinguish between two regimes, where the non-adopters (Di = 0) is taken as the reference category. The outcome equations used in the MESR model can be specified as follows.

$$Regime \ 1 \ (Adopters): Y1i \ = \ X1i\beta 1 \ + \ \Theta 1\lambda 1i \ + \ \varepsilon 1i \ if \ Di \ = \ 1 \ (2)$$

$$Regime \ 2 \ (Non - adopters): Y2i \ = \ X2i\beta 2 \ + \ \Theta 2\lambda 2i \ + \ \varepsilon 2i \ if \ Di \ = \ 0 \ (3)$$

Y1i and Y2i signify the respective food security outcomes for adopting and non-adopting households.

Xji represents the vector of exogenous covariates predicting the outcome metrics.

ε1i and ε2i are the error terms, assumed to have a mean of zero and constant variance.

λji represents the Inverse Mills Ratio (IMR) computed from the first-stage selection equations. This ratio controls for selection bias stemming from unobserved heterogeneity(Zegeye et al., 2026);(Sedebo et al., 2022); (Tung et al., 2024).

This framework can also give us the expected food security status for both groups. We can contrast the outcomes of real adopters compared to what would have happened to them if they had not adopted by taking the difference between the outcomes for adopters (Q) and the predicted outcomes if they had not adopted (R). This gives us the Average Treatment Effect on the Treated (ATT).

In contrast, the Average Treatment Effect on the Untreated (ATU) is a measure of how much the potential outcome for non-adopters if they chose to adopt (T) differs from their actual outcome (S). (Table 2) Following (Di Falco, Veronesi, & Yesuf, 2011), these estimations are formally expressed in the following Eq.

$$ATT = E[Y1i|\, Di = 1] - E[Y0i|\, Di = 1]\ (4)$$
$$ATU = E[Y1i|\, Di = 0] - E[Y0i|\, Di = 0]\ (5))$$

3. Results and discussion

The econometric model results are presented in this section. Descriptive statistics are also included.

3.1. Descriptive results

Descriptive analysis of 325 households indicates a preference for combined adaptation strategies, with the full strategies (livelihood diversification, herd mobility, and rangeland management) being the most prevalent at 35.38% (Choice 7: L1H1R1).” Whereas Livelihood Diversification and Rangeland Management (Choice 5) were 2nd most popular with 18.77%, none of the measure was only 5.54% for households.” For detailed analysis, refer to the provided tabulated data on multinomial packages, frequencies, and percentages. Table 2 presents the descriptive statistics and mean comparison tests for the food security outcome variables across the different climate change adaptation strategy packages. The sample population, on average, has a moderate Household Dietary Diversity Score (HDDS) of 6.25 and Food Consumption Score (FCS) of 34.36, suggesting moderate food security. However, disaggregating the data by multinomial adoption packages reveals striking variations between non-adopters and those adopting single or combined adaptation strategies. This is supported by (Zakari et al., 2022)

Table 4Alternative Adaptation Strategy Adoption and Frequency

Choice	Multinomial Packages	Livelihood Diversification		Herd Mobility		Rangeland Management		Frequency	Percentage
		L_0	L_1	H_0	H_1	R_0	R_1		
0	$L_0H_0R_0$	✓		✓		✓		18	5.54

1	$L_1H_0R_0$		✓	✓		✓		13	4.00
2	$L_0H_1R_0$	✓			✓	✓		21	6.46
3	$L_0H_0R_1$	✓		✓			✓	42	12.92
4	$L_1H_1R_0$		✓	✓		✓		31	9.54
5	$L_1H_0R_1$		✓	✓			✓	61	18.77
6	$L_0H_1R_1$	✓		✓			✓	24	7.38
7	$L_1H_1R_1$		✓		✓		✓	115	35.38

Note: Each element in the combination is a multinomial variable where the subscripts represent 1 = adoption and 0 = non-adoption. Choice 0 represents non-adoption of any strategy ($L_0H_0R_0$); 1 is for livelihood diversification only ($L_1H_0R_0$); 2 is for herd mobility only ($L_0H_1R_0$); 3 is for rangeland management only ($L_0H_0R_1$); 4 is for livelihood diversification and herd mobility ($L_1H_1R_0$); 5 is for livelihood diversification and rangeland management ($L_1H_0R_1$); 6 is for herd mobility and rangeland management ($L_0H_1R_1$); and 7 is for the joint adoption of all three strategies ($L_1H_1R_1$).

Impact on Household Dietary Diversity (HDDS)

Non-adopting households ($L_0H_0R_0$) suffer from severe dietary limitations, recording the lowest average HDDS of 2.33. Crucially, the adoption of even a single adaptation strategy leads to a statistically significant increase in dietary diversity ($P<0.01$) relative to non-adopters, with single-strategy scores ranging from 3.23 ($L_1H_0R_0$) to 4.19 ($L_0H_1R_0$). Dietary diversity scales up progressively with the number of strategies combined. Households combine two practices exhibit higher means, with the ($L_1H_0R_1$) package (livelihood diversification and rangeland management) reaching an HDDS of 6.13. The highest dietary diversity is achieved by households implementing the full combination of all three practices ($L_1H_1R_1$), increased a mean HDDS of 8.45. This confirms that joint adoption offers the strongest synergistic benefits for household food access. This result is in line with (Begashaw et al., 2024).

Impact on Food Consumption Scores (FCS)

The baseline food consumption score for non-adopters stands at 17.44, which falls deep within the WFP "Poor" food consumption threshold (<21). Unlike the pattern observed with HDDS, the single adoption of livelihood diversification alone ($L_1H_0R_0$), mean = 18.23) fails to yield a statistically significant improvement over non-adopters, leaving households trapped in the "Poor" consumption zone. However, any adaptation strategy incorporating either herd mobility H_1 or rangeland management R_1 generates a structural break, achieving highly significant gains ($P<0.01$) relative to the reference group. Single adoption of these strategies elevates households into the "Borderline" food consumption zone (21.5 to 35), as seen in $L_0H_1R_0$ (23.14) and $L_0H_0R_1$ (24.02). Combinations of two strategies further optimize dietary frequency, pushing scores toward the upper bound of the borderline category. Ultimately, only the packages that heavily lean on multiple strategies specifically $L_1H_1R_1$ (37.96) and the complete three-practice package $L_0H_1R_1$ (44.80) succeed in structurally transitioning vulnerable households into the "Acceptable" food consumption threshold (>35).

Table 5Descriptive results for the outcome variables used in the regression

Outcome variable	$L_0H_0R_0$	$L_1H_0R_0$	$L_0H_1R_0$	$L_0H_0R_1$	$L_1H_1R_0$	$L_1H_0R_1$	$L_0H_1R_1$	$L_1H_1R_1$	Overall
HDDS	2.33	3.23***	4.19***	4.12***	5.29***	6.13***	7.37***	8.45***	6.25
	(0.48)	(0.12)	(0.40)	(0.74)	(0.46)	(0.34)	(0.49)	(1.27)	
FCS	17.44	18.23	23.14***	24.02***	30.03***	34.87***	37.96***	44.8***	34.36
	(3.45)	(3.76)	(3.02)	(3.42)	(3.23)	(1.43)	(3.49)	(8.59)	

Note: Mean values are reported for each adoption adaptation strategies with standard deviations in parentheses. Choice 0 ($L_0H_0R_0$) serves as the reference group (non-adopters) for the mean comparison tests. *** indicates statistical significance at the 1% level ($p < 0.01$) relative to the reference group based on two-sample t-tests. HDDS = Household Dietary Diversity Score (scale: 0–12); FCS = Food Consumption Score (scale: 0–112).

3.2. Impact of Adaptation Strategy on the Household Dietary Diversity Score (HDDS)

Simple mean comparisons of Household Dietary Diversity Scores (HDDS) across different adoption groups can lead to biased conclusions, as they fail to account for unobserved household characteristics that influence both the adoption decision and food security outcomes. To address this self-selection bias, an Endogenous Switching Regression (ESR) framework was applied. Table 3 presents the true causal impacts of Climate Change Adaptation Strategies (CCAS) package adoption on HDDS by mapping observed and counterfactual expected values for both adopting and non-adopting pastoral and agropastoral households.

The empirical estimates reveal that the Average Treatment Effect on the Treated (ATT) is positive and statistically significant at the 1% level across all seven adaptation strategies. This demonstrates that adoption of these adaptation strategies causes a clear, structural improvement in household food access. For pastoral and agro-pastoral households that actually adopted single practices, the causal increase in dietary diversity ranges from 2.36 food groups for livelihood diversification alone L1H0R0 to 3.05 food groups for standalone rangeland management L0H0R1 compared to their counterfactual scenario of non-adoption. Importantly, compounding these adaptation choices triggers massive synergetic benefits. Households deploying two strategies realize substantially larger gains, spearheaded by the combination of livelihood diversification and rangeland management (L1H1R0), which generates an ATT of 4.78. The absolute peak in food access benefits is captured by households executing the entire three-pronged package L1H1R1. Under this full combination, adopters score an actual HDDS of 8.45, whereas their counterfactual baseline without adoption would drop to just 1.85. This food diet has a massive, highly significant ATT of 6.61 additional food groups, proving that comprehensive adoption acts as the ultimate buffer against climate-induced ...dietary insecurity. This finding is in line with (Admasu et al., 2024a) ;(Begashaw et al., 2024).

Average Treatment Effects on the Untreated (ATU)

The counterfactual analysis for non-adopting households measured through the Average Treatment Effect on the Untreated (ATU) presents equally vital economic evidence. If pastoral and agropastoral households that currently do not adopt any strategies were to adopt, their HDDS would rise significantly ($p < 0.01$) relative to their current baseline of 2.33.The simulated gains range from a minimum of 1.29 food groups under standalone rangeland management $L_0H_0R_1$ up to a remarkable 5.66 food groups if they embraced the full, integrated package $L_1H_1R_1$. This highlights a critical policy bottleneck: non-adopters are facing a high food-security opportunity costs of remaining unadapted, implying that substantial entry barriers(such as capital constraints, lack of extension services, or limited communal resources) may be blocking their capacity to adopt.

Endogenous Heterogeneity and Transitional Impacts

The bottom block of Table 3 explicitly accounts for structural differences between the two sub-populations using heterogeneity metrics. The base heterogeneity effects for non-adopters (BH0) are negative and highly significant ($p < 0.01$) across every single package choice. This indicates that in the hypothetical state of universal non-adoption, households that actually chose to adopt would still have scored worse dietary metrics than the natural non-adopters. This confirms that those who chose to adopt were initially the most vulnerable households, driven to adapt by structural necessity.

Crucially, the transitional heterogeneity (TH) index evaluates whether the net reward of adoption is structurally higher for the actual adopters than for the non-adopters. Except for the standalone livelihood diversification package $L_1H_0R_0$, the TH estimates are positive and highly statistically significant across all strategies. For example, the net structural advantage (TH) spans from 1.23 for the $L_1H_0R_1$ package to 1.91 for the $L_1H_1R_0$ strategies. These positive TH values validate the economic rationale of these pastoral and agropastoral households: those who chose to implement these specific climate change adaptation strategies are precisely the ones who derive the largest marginal gains from them. This structural advantage confirms that the allocation of adaptation strategies across this rural sample is not random, but rather a reflection of self-selective, utility-maximizing behavior where households capitalize on their specific unobserved resource endowments(Begashaw et al., 2024)

Table 6.Endogenous Switching Regression Estimates for the Average Treatment Effects of CCAS Adoption on Household Dietary Diversity Scores (HDDS)

Household Dietary Diversity Score	CSA Packages	Decision stage		Average Treatment effects
		To adopt	Not to adopt	
				Treated
PA&APhouseholds That Adopted	$L_1H_0R_0$	3.23(0.12)	0.87(0.24)	2.36***(0.28)
	$L_0H_1R_0$	3.55(0.37)	1.06(0.21)	2.49***(0.42)
	$L_0H_0R_1$	4.12(0.07)	1.06(0.12)	3.05***(0.15)
	$L_1H_1R_0$	5.29(0.06)	1.70(0.10)	3.58***(0.12)
	$L_1H_0R_1$	6.13(0.02)	1.35(0.12)	4.78***(0.12)

	$L_0H_1R_1$	7.37(0.09)	1.79(0.17)	5.58***(0.20)
	$L_1H_1R_1$	8.45(0.05)	1.85(0.06)	6.61***
				Untreated
	$L_1H_0R_0$	5.32(0.41)	2.33(0.06)	2.99***(0.41)
	$L_0H_1R_0$	3.91(0.43)	2.33(0.06)	1.57***(0.44)
	$L_0H_0R_1$	3.63(0.34)	2.33(0.06)	1.29***(0.34)
That didn't	$L_1H_1R_0$	4.00(0.37)	2.33(0.06)	1.66***(0.38)
Adopted	$L_1H_0R_1$	5.88(0.07)	2.33(0.06)	3.55***(0.09)
	$L_0H_1R_1$	7.33(0.21)	2.33(0.06)	5.00***(
	$L_1H_1R_1$	7.99(0.22)	2.33(0.06)	5.66***(0.22)
		BH1	BH0	TH
	$L_1H_0R_0$	-2.09***(0.49)	-1.47***(0.22)	-0.63(0.51)
	$L_0H_1R_0$	0.28(0.41)	-1.27***(0.24)	1.55***(0.46)
Transitional and	$L_0H_0R_1$	0.49*(0.24)	-1.26***(0.19)	1.76***(0.33)
Heterogeneity	$L_1H_1R_0$	1.29***(0.29)	-0.62***(0.14)	1.91***(0.33)
Effects	$L_1H_0R_1$	0.25***(0.05)	-0.98***(0.22)	1.23***(0.24)
	$L_0H_1R_1$	0.04(0.21)	-0.54**(0.21)	0.58**(0.28)
	$L_1H_1R_1$	0.455***(0.15)	-0.49***(0.16)	0.94***(0.21)

Note: Values are reported as means with standard errors in parentheses. Column (5) presents the Average Treatment Effect on the Treated (ATT) for pastoral and agropastoral households that adopted and the Average Treatment Effect on the Untreated (ATU) for pastoral and agropastoral households that did not adopt. BH1 represents the base heterogeneity effect for adopters; BH0 represents the base heterogeneity effect for non-adopters; and TH represents the transitional heterogeneity effect (the net structural advantage of adoption). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. L = Livelihood Diversification; H = Herd Mobility; R = Rangeland Management. (L1, H1, R1) represent adoption, while (L0, H0, R0) represent non-adoption.

Evaluating the Causal Impacts of Climate Change Adaptation Strategy Packages on Household Food Security: An Endogenous Switching Regression Approach

The Endogenous Switching Regression (ESR) results reveal that the Average Treatment Effect on the Treated (ATT) is positive and statistically significant at the 1% level across all seven climate change adaptation strategy. This confirms that the adoption of these strategies has a true causal, positive effect on household dietary quality and consumption frequencies, independent of selection bias. For actual adopters of isolated single strategies, the causal increases in Food Consumption Scores (FCS) range from 9.64 points for standalone livelihood diversification $L_1H_0R_0$ to 17.93 points for isolated rangeland management $L_0H_0R_1$ compared to their counterfactual states of non-adoption. Compounding these adaptation measures more diverse food consumption, escalating rewards. Households that transition into multi-strategy frameworks show a sharp upwards shift in consumption frequencies. Adopters of

the two-strategy packages reach significant increases of 16.03($L_1H_1R_0$), 24.57($L_1H_0R_1$), and 24.06 ($L_0H_1R_1$) points over their counterfactual thresholds. The peak consumption benefit is captured by pastoral and agropastoral households executing the complete three-pronged adaptation strategies $L_1H_1R_1$. Under this full combination, adopters register an actual mean FCS of 44.80, safely placing them within the World Food Programme's "Acceptable" food consumption zone (>35). Had they chosen not to adopt, their counterfactual baseline score would have collapsed to a dismal 14.58, trapping them deep within the "Poor" food consumption zone (<21). This structural shift translates into a massive, highly significant ATT of 30.21 points, demonstrating that comprehensive adoption provides the ultimate safety net for rural households under climate stress this finding confirmed by (Admasu et al., 2024a; Sawadogo et al., 2025); (Begashaw et al., 2024).

Table 7Endogenous Switching Regression Estimates for the Average Treatment Effects of CSAS Adoption on Household Food Consumption Scores (FCS)

FCS	CSA Packages	Decision stage		ATE
		To adopt	Not to adopt	
				Treated
	$L_1H_0R_0$	18.23(1.04)	8.59(1.52)	9.64***(1.84)
	$L_0H_1R_0$	23.14(0.64)	9.39(1.23)	13.74***(1.39)
PA&AP households	$L_0H_0R_1$	24.02(24.02)	6.08(0.95)	17.93*** (1.04)
That Adopted	$L_1H_1R_0$	30.03(0.46)	14.00(0.65)	16.03***(0 .79)
	$L_1H_0R_1$	34.86(0.11)	10.29(0.87)	24.57***(0 .88)
	$L_0H_1R_1$	37.95(0.70)	13.89(1.06)	24.06***(1.27)
	$L_1H_1R_1$	44.8(0.36)	14.58(0.39)	30.21***(0.54)
				Untreated
	$L_1H_0R_0$	12.13(5.21)	17.44(0.42)	-5.31(5.23)
	$L_0H_1R_0$	18.78 (3.18)	17.44(0.42)	1.337077 3.21
	$L_0H_0R_1$	20.46 (1.66)	17.44(0.42)	3.02*(1.71)
That didn't	$L_1H_1R_0$	21.00(2.61)	17.44(0.42)	3.5558 2.64
Adopted	$L_1H_0R_1$	33.46 (0.23)	17.44(0.42)	16.02***(0.48)
	$L_0H_1R_1$	17.44(0.42)	17.44(0.42)	19.83***(1.49)
	$L_1H_1R_1$	56.22(3.13)	17.44(0.42)	38.78***(3.16)
		BH1	BH0	TH
	$L_1H_0R_0$	6.09(6.23)	-8.85***(1.37)	14.95***(6.20)
	$L_0H_1R_0$	4.36(3.02)	-8.04***(1.39)	12.40**(3.28)
Transitional and	$L_0H_0R_1$	3.56***(1.26)	-11.35***(1.48)	14.91***(2.16)
Heterogeneity	$L_1H_1R_0$	9.03***(2.06)	-3.44***(0 .91)	12.47***(2.21)
Effects	$L_1H_0R_1$	1.40***(0.25)	-7.15***(1.63)	8.55***(1.75)
	$L_0H_1R_1$	0.68(1.48)	-3.54***(1.28)	4.23**(1.94)

	$L_1H_1R_1$	-11.42***(1.53)	-2.85***(1.02)	-8.56***(1.71)

Note: Values are reported as means with standard errors in parentheses. Column (5) presents the Average Treatment Effect on the Treated (ATT) for Pastoral and Agropastoral households that adopted and the Average Treatment Effect on the Untreated (ATU) for pastoral and agropastoral households that did not adopt. The final row block displays transitional heterogeneity impacts: BH_1 represents the base heterogeneity effect for adopters; BH_0 represents the base heterogeneity effect for non-adopters; and TH represents the transitional heterogeneity effect (the net structural advantage of adoption). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. FCS = Food Consumption Score (scale: 0–112); L = Livelihood Diversification; H = Herd Mobility; R = Rangeland Management. Subscripts 1 and 0 denote adoption and non-adoption, respectively(Admasu et al., 2024a).(Sawadogo et al., 2025)

4. Conclusions and Recommendations

Ethiopians, including South Omo pastoralists and agropastoralists, employ a variety of adaptation and coping strategies to mitigate the unpredictable impacts of climate change. Various adaptation strategies to cope with climate change can influence nutritional outcomes positively or negatively. It's essential to choose climate change adaptation strategies that consider nutrition, with two frameworks focusing on food and nutrition security. The descriptive result shows that households indicate a preference for combined adaptation strategies, with livelihood diversification, herd mobility, and range land management being the most prevalent at 35.38% (Choice 7: L1H1R1). While Livelihood Diversification and Rangeland Management (Choice 5) was the second most popular choice at 18.77%, only 5.54% of households adopted none of the measures.

Multinomial endogenous switching regression model estimation found that adopting climate change adaptation strategies, particularly combinations of strategies, can significantly improve dietary diversity. This suggests that for pastoral and agropastoral households that actually adopted single practices, the causal increase in dietary diversity ranges from 2.36 food groups for livelihood diversification alone L1H0R0 to 3.05 food groups for standalone rangeland management L0H0R1 compared to their counterfactual scenario of non-adoption. For actual adopters of isolated single strategies, the causal increases in Food Consumption Scores (FCS) range from 9.64 points for standalone livelihood diversification L1H0R0 to 17.93 points for isolated rangeland management L0H0R1 compared to their counterfactual states of non-adoption. These findings highlight the importance of livelihood portfolio diversification strategies in improving household food diversification and increasing food frequencies. By diversifying their livelihood items, individuals can better withstand shocks and stresses that may impact their primary source of income. This underscores the need for pastoralists and agro-pastoralists to adopt a range of adaptation strategies to reduce their susceptibility to food and nutrition security in the face of uncertain climate change events. Consequently, it is recommended that policymakers and stakeholders increase support for pastoral

and agro-pastoral adaptation and integrate these strategies into development plans to improve household nutrition and climate resilience in the study area.

Declarations

Ethical approval

This study was conducted in accordance with the ethical standards of the institutional research committee and the 1964 Helsinki Declaration and its later amendments. Formal ethical approval was granted by the Institutional Review Board (IRB) of Jimma University (Approval No. 512).

Consent to participate

Prior to data collection, all participants were fully informed regarding the study's objectives, data handling procedures, and storage protocols. Written informed consent was obtained from each respondent before their participation in interviews or the collection of data.

Consent for publication

Informed consent for the publication of anonymized research data and findings was obtained from all individual participants prior to inclusion in the study.

Clinical Trial registration

Not applicable

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Credit authorship contribution statement

- **Gishu Nigatu Haregu**: writing: conceptualization, formal analysis, methodology, supervision, data curation, and initial draft.
- **Adugna Eneyew Bekele**: Data curation, supervision, methodology, formal analysis, and conceptualization. The final draft of the manuscript has been read and approved by all writers.
- **Teferi Tolera**: writing: conceptualization, formal analysis, methodology, supervision, data curation, and initial draft.
- **Dereje Hamza**: Data curation, supervision, methodology, formal analysis, and conceptualization. The final draft of the manuscript has been read and approved by all writers

Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author contribution declaration

- **Gishu Nigatu Haregu**: Writing: Conceptualization, formal analysis, methodology, supervision, data curation and first draft.
- **Adugna Eneyew Bekele**: Data curation, supervision, methodology, formal analysis and conceptualization.
- **Teferi Tolera**: Data curation, supervision, methodology, formal analysis and conceptualization.
- **Dereje Hamza**: Data curation, supervision, methodology, formal analysis and conceptualization. This manuscript's final draft was read and approved by all authors.

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