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Are climate change adaptation strategies interrelated? Evidence from Borana pastoral communities, southern Ethiopia

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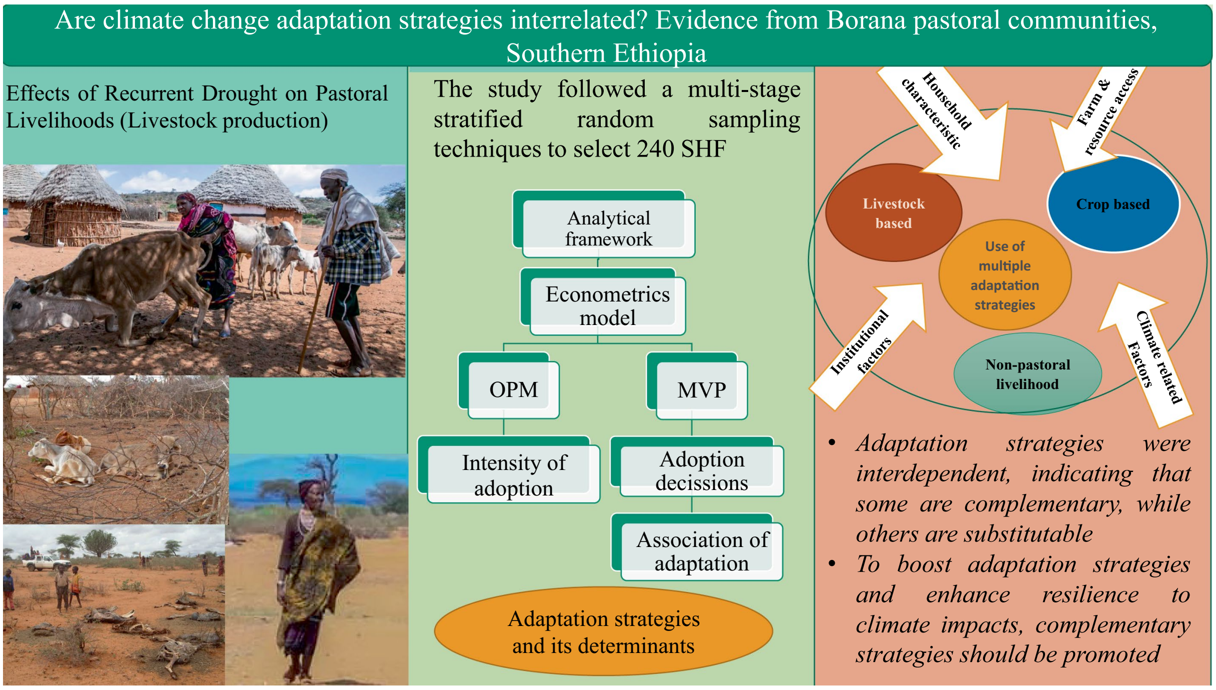
Climate change manifests itself in recurrent droughts and erratic rainfall, resulting in diminished local water and animal feed resources. This has led to the death of large numbers of livestock, which are the basis of pastoral livelihoods in the Borana Zone, southern Ethiopia. In response to climate change impacts, the Borana pastoral community adopted various adaptation strategies to sustain their livelihoods. The present study examined the factors that determine pastoralists' adaptation strategies and the intensities of their adoption and identified barriers to their implementation. A multivariate probit (MVP) and an ordered probit model were employed to analyze the adoption decisions of 240 households and a problem confrontation index to identify barriers to the adoption of adaptation strategies. The results indicate that while there are various adaptation strategies, some have a very low adoption rate. The majority of households (90%) used at least two of these adaptation strategies, and only 1.67% used all of them. Most importantly, the majority of adaptation strategies were interdependent, which indicates that some strategies are complementary and others are substitutable. Promoting complementary strategies within a package may help boost adaptation strategies and enhance resilience to the impacts of climate change through their synergies. Education, the dependence ratio, farming activity, access to extension services, and market distance significantly affect adoption decisions and adoption intensity. Similarly, bush encroachment, regionalization policies, improper settlement patterns, and farmland expansion hinder the implementation of adaptations. Hence, interventions that facilitate the adoption of climate change adaptation strategies and address barriers to their implementation can improve pastoral and agro-pastoral resilience to climate change. It would also be crucial to develop land-use planning that encourages the coexistence of livestock grazing and crop cultivation in order to maintain ecological balance and minimize conflict.

KEYWORDS

adaptation strategy, agro-pastoral, barriers, climate change, pastoral, multivariate, ordered probit model



GRAPHICAL ABSTRACT

1 Introduction

Globally, climate change is one of the most pressing issues and challenges of the 21st century (UNFCCC, 2007). According to the recent assessment report from the International Panel on Climate Change, climate change has been showing increasing trends and is expected to worsen its extreme variability in the future (IPCC, 2019). Global average sea level rise, melting snow and ice, and rising global air and ocean temperatures are some of the signs of climate change. Changes in precipitation patterns, a rise in global mean temperature, and extreme weather events, including flooding and drought, have been observed in recent years (IPCC, 2007).

During the last 50 years, for instance, Ethiopia's annual temperature has increased by about 0.2°C every decade (EPCC, 2015). The report indicates that the increase in minimum temperatures is more pronounced, with roughly 0.4°C per decade. Unfavorable shifts in rainfall are also followed by a serious drought, which nowadays recurs every year to 2 years, especially in the lowlands of Ethiopia (NAPA, 2007; EPCC, 2015). Extreme weather conditions, such as floods, excessive precipitation, and heat waves, are manifestations of climate variability (EPCC, 2015). As droughts have become more frequent and intense, pastoral communities that are situated in the most fragile, low-lying areas of the country and whose livelihoods solely depend on rain-fed pastoralism and agriculture are more at risk (Ayal et al., 2015, 2018; Berhanu and Beyene, 2015).

Drought has recurred in Ethiopian lowlands throughout history, and traditional systems of social organization and resource management have adapted to these changes (Riché et al., 2009). Over the past decades, for example, the Borana lowland has experienced more frequent drought than previously recorded. This condition has resulted in decreased water and forage resources, increased animal diseases and parasites, and significant livestock losses, which are essential for pastoral livelihoods (Megersa, 2013; Megersa et al., 2014; Wako et al., 2017). Due to prolonged drought in 2021–22, for instance, the ever-increasing temperature and the failure of two consecutive main rainy seasons (Gana) resulted in a devastating drought, which decimated massive livestock populations of about 3.2 million and deepened the level of poverty and pastoralist food insecurity in the Borana lowland (Cullis and Bogale, 2024).

Over time, pastoral communities have developed a variety of adaptation strategies to minimize their vulnerability to climate change (Tache and Sjaastad, 2010; Omolo, 2011). Among the different adaptation strategies that Borana pastoralists and agro-pastoralists use are livestock-based adaptation (herd mobility, livestock diversification, destocking, feed preservation, and livestock insurance), cereal cultivation (crop diversification, improved crop variety), and off-farm incomes (Berhanu and Beyene, 2014; Wako et al., 2017; Ayal et al., 2018). Pastoralism is a livelihood strategy that primarily depends on livestock production for food, clothing, shelter, and income; they often migrate with their herds to find water and grazing pasture. Whereas, agropastoral is a mixed livelihood system that combines both livestock production and crop farming. As climate scientists predict increased drought events in the region, Borana pastoralists will likely continue to face stress and hardship, even if adaptation strategies have enabled them to cope with the climate-related shock (Hurst et al., 2012). In addition to this, Niles and Mueller (2016) noted that Ethiopian pastoralists are increasingly unable to sustain their livelihoods during drought through traditional adaptation strategies. As a result, continuous monitoring and research are needed to better understand climate change impacts, adaptation strategies, and how they are evolving (Riché et al., 2009), and factors influencing choices of adaptation strategies to build a climate-resilient livelihood system to ensure food security. Understanding and characterizing the nature of adaptation strategies, their interdependence, and how their association affects the uptake of adaptation strategies,

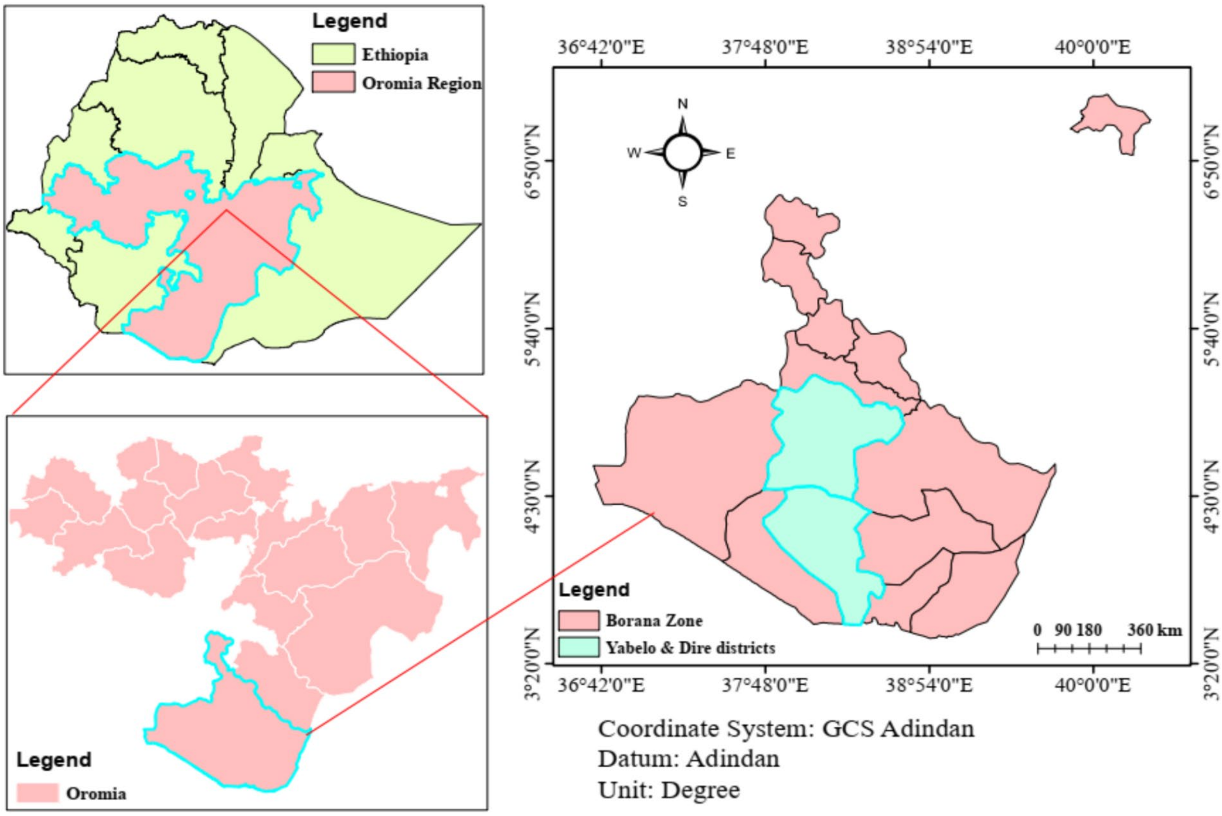


FIGURE 1
Map of the study area.

what motivates people to choose a specific package from the available options, and the existing barriers are important areas of research and policy development (Debela et al., 2015; Ayal et al., 2018; Fentie et al., 2020; Gemeda et al., 2023). This interdependence is important as it allows for a comprehensive understanding of how the adaptation strategies can be effectively combined to enhance resilience to climate change impacts. By identifying the complementary or substitutive characteristics of different approaches, stakeholders can effectively and efficiently allocate their resource and develop plan. This, in turn, leads to more robust and sustainable adaptation outcomes.

Several studies have attempted to assess climate change impacts, adaptation strategies, and factors influencing adaptation decisions in mixed crop-livestock farming systems in Ethiopia (Deressa et al., 2008; Gemeda et al., 2023; Tamene et al., 2023). There have also been studies that examine how climate change affects pastoral livelihoods, as well as adaptation measures and factors that influence pastoralists' choices of adaptation strategies in the study area (Berhanu and Beyene, 2015; Ayal et al., 2018; Tamene et al., 2023). In spite of their substantial contribution to science, some of these studies fail to account for the intensities of adaptation strategies and their associations, which may influence pastoralists' adoption decisions, or fail to consider the range of adaptation strategies that can complement or substitute each other in the analytical model used. However, pastoral and agro-pastoral communities rely on a variety of adaptation strategies that can be used in combination to enhance productivity, mitigate, and adapt to climate change. Recent empirical evidence shows that joint adaptation strategies significantly increase productivity, net income, and resilience to climate change impacts (Wekesa et al., 2018; Zakari et al., 2022; Tetteh et al., 2023). In addition, the choice of new adaptation strategies by pastoralists and agro-pastoralists may be influenced by their current adaptation strategies. Therefore, it is crucial to develop more comprehensive analytical models to examine the factors influencing households' adoption decisions and barriers to adaptation, while accounting for complexity, scale, and interdependence. The study examined factors affecting climate change adaptation strategies and barriers to adaptation using multivariate and ordered probit models.

Based on the given premises, the current study presents the following hypothesis:

> *Hypothesis 1*: Environmental, socio-economic, and technological factors significantly influence decision to adaptation strategies.
>
> *Hypothesis 2*: Climate change adaptation strategies used by pastoral/agro-pastoral communities are interdependent.

2 Methodology

2.1 Study area

This study was carried out in the Yabello and Mega districts of the Borana Zone, southern Ethiopia (Figure 1). The Borena zone is located in southern Ethiopia between 3° 36′–6° 38' N and 36° 43′–41° 40′E. The area is classified as arid and semi-arid rangeland with pockets of sub-humid zones (Coppock, 1994). The rainfall is bimodal with a mean annual rainfall of 500 mm (Angassa and Oba, 2007), with

60% occurring during the main rainy season and 30% in the short season (Coppock, 1994). The longest dry period occurs between December and February, and the coolest period occurs between June and August. Temperatures vary from 18°C to 29°C on an annual basis, with a mean of 24°C (Coppock, 1994; Bogale et al., 2025).

A remarkable characteristic of the plateau is the presence of a cluster of nine deep wells known as "Tulas." These wells serve as a crucial and indispensable resource that drives the pastoral production system (Cossins and Upton, 1987; Coppock, 1994). Beyond their role in providing a permanent water supply, the "*Tula*" wells hold immense significance in Borana society, serving as a cultural symbol, a focal point for social organization, and a site for ritual practices (Tiki et al., 2011). Tropical savannah vegetation dominates the Borana rangelands, varying between open grasslands and perennial wooded areas (Coppock, 1994). The primary livelihood activities of the local population revolve around pastoralism and agro-pastoralism, as they have adapted to climate change and spatial–temporal variations in forage production (Coppock, 1994; Tiki et al., 2011; Tetteh et al., 2023). Pastoralism and agro-pastoralism are the dominant economic activities for people. Pastoralists depend on livestock production and cereal cultivation for their livelihoods. Climate variability, however, limits the benefit of these additional livelihood endeavors due to the unpredictable nature of harvesting crops.

2.2 Sampling and data collection

Sample districts, kebeles (small administrative units), and households were selected through a multi-stage sampling technique combining purposive and random sampling procedures. In the initial stage, two districts, namely Yabello and Dirre, were purposively selected out of the 13 districts in the Borana Zone. These districts were selected to represent distinct water sources, with Dirre representing a Tula-well ecosystem and Yabello representing a non-Tula (referred to as Adadi) well ecosystem. Moving to the second stage, three Kebeles were purposively selected from each district in consultation with local administrators and pastoral development office experts. Communities exposed to recurrent droughts were also considered in the selection process. Participants in the selected sample of kebeles were stratified into two groups: pastoral and agro-pastoral. By using a simple random sampling technique using proportional sample size, 156 pastoral households and 84 agro-pastoral households were selected in proportion to their representation in the population. Finally, a total of 240 sample households was determined following the procedure used by Yamane (1967), which assumes 50% ($p = 0.5$) variability and 95% confidence level with ± % precision error.

$$n = \frac{N}{1 + N\left(e\right)^2}.$$

Where:

- n is the sample size;
- N is the population size;
- e is the level of precision.

Both qualitative and quantitative data were gathered from primary and secondary sources. To collect data, key informant interviews, focus group discussions, formal household surveys, as well as secondary sources, were used. The collected data encompasses detailed information on households' demographic and socio-economic characteristics, pastoralists' perception of climate change and variability (CCV) over the past years and its impacts on their livelihood activities, and adaptation options practiced by pastoral communities. The primary data obtained from the field survey was triangulated with the data from Focus Group Discussions (FGD) and Key Informant Interview (KII). Literature and government agencies were used as secondary sources.

2.3 Data analysis

Descriptive statistics, an econometric model, and a Problem Confrontation Index (PCI) ranking were employed to analyze data collected from a household survey. Descriptive statistics such as mean, standard deviation, coefficient of variation, and percentage were used to analyze household socioeconomic and demographic characteristics. PCI ranking was used to assess the main barriers to the implementation of climate change adaptation. A multivariate and ordered probit model was used to analyze the determinants of pastoralists' and agro-pastoralists' adaptation strategies and the intensity of adaptation (Kpadonou et al., 2017; Muluye et al., 2017; Teklewold et al., 2019). The model is an analytical approach that is commonly used in adoption decision studies involving multiple choices. Considering the possibility of a correlation between unobserved disturbances in the adoption equations, Belderbos et al. (2004) propose that MVP models to estimate the impact of several independent variables on different practices. This approach examines how a complementarity (positive correlation) or substitutability (negative correlation) between adaptation strategies may influence the decision to adopt one strategy over another. Accordingly, the decision to adopt a particular practice may depend on the adoption of another practice. According to Greene (2003), failure to capture the interrelationships among adoption decisions leads to bias and inefficient estimates.

Multivariate probit model: Exposed to adverse climatic changes, pastoral communities may opt to adopt a mix of adaptation strategies to mitigating the adverse effects rather than relying on a single strategy to exploit complementarities among alternatives. The MVP model is formulated according to random utility theory (RUT). According to this theory, a pastoral or agro-pastoral community is more likely to adopt a specific adaptation strategy if the expected utility of its adoption is higher than non-adoption (Leonardi, 1981; Leonardi and Tadei, 1984; Andersson and Ubøe, 2010).

To describe the MVP model, let the i^{th} household ($i = 1\ldots$, N) that is facing a decision on whether to adopt available j adaptation practices or not. Here j^{th} stands for livestock-based (herd mobility, livestock diversification (LSD), destocking, feed preservation (FP), and Livestock Insurance (LS Insurance), crop-based (improved crop variety (ICV), crop diversification (CD), and off-farm income (OFI) adaptation strategies. Let Uj denote the benefits to the pastoral and agro-pastoral from adopting j^{th} adaptation strategies and let Uo represent the benefits to the household from non-adoption. The household will decide to adopt the j^{th} strategies on the farm if $Y^*_{ipj} = U_j^* - Uo > 0$. The net utility from adopting the j^{th} practice is a latent variable defined by observable home and farm characteristics

(X'$_{ip}$) and the normally distributed error term (X'_{ip}). Then, the multivariate probit model can be constructed as follows:

$$Y_{ipj}^{*} = X_{ip}^{'}\beta_j + \varepsilon_{ip} \left(j = Mob.,LSD,Des,FP,LSI,CD,ICV\ and\ OFI \right) \quad (1)$$

In Equation (1), the unobserved binary choices can be transformed into the observed binary outcome Equation (2) as follows:

$$Y_{ij} = \begin{cases} 1\, if\ Y_{ipj}^{*} > 0 \\ 0\, otherwise \end{cases}$$
$$\left(j = Mob,LSD,Hay,Destock,CD,ICV,SB,and\ FWS \right) \quad (2)$$

Where:

- Y_{ij} is a dichotomous observable variable that indicates the decision of i^{th} household to adopt j^{th} adaptation strategies.

For MVP, which allows the use of multiple strategies, the error terms are assumed to follow a multivariate normal distribution (MVN), with a mean of zero and variance of one, i.e., ($\cup_{Mob}$, $\cup_{LSD}$,$\cup_{Dest}$, $\cup_{FP,}$ $\cup_{LSI,}$ $\cup_{ICV,}$ $\cup_{CD,}$ $\cup_{OFI}$) ~ MVN (0, Ω), where Ω is the symmetric covariance matrix given by the following Equation (3):

$$\Omega = \begin{bmatrix} 1 & \rho_{M,LSD} & \rho_{M,D} & \rho_{M,FP} & \rho_{M,LSI} & \rho_{M,ICV} & \rho_{M,CD} & \rho_{M,OFI} \\ \rho_{M,LSD} & 1 & \rho_{LSD,D} & \rho_{LSD,FP} & \rho_{LSD,CV} & \rho_{LSD,ICV} & \rho_{LSD,CD} & \rho_{LSD,OFI} \\ \rho_{M,D} & \rho_{LSD,D} & 1 & \rho_{D,FP} & \rho_{D,LSI} & \rho_{D,ICV} & \rho_{D,CD} & \rho_{D,OFI} \\ \rho_{M,FP} & \rho_{LSD,FP} & \rho_{D,FP} & 1 & \rho_{FP,LSI} & \rho_{FP,ICV} & \rho_{FP,CD} & \rho_{FP,OFI} \\ \rho_{M,LSI} & \rho_{LSD,LSI} & \rho_{D,LSI} & \rho_{FP,LSI} & 1 & \rho_{LSI,ICV} & \rho_{LSI,CD} & \rho_{LSI,OFI} \\ \rho_{M,ICV} & \rho_{LSD,ICV} & \rho_{D,ICV} & \rho_{FP,ICV} & \rho_{LSI,ICV} & 1 & \rho_{ICV,CD} & \rho_{ICV,OFI} \\ \rho_{M,} & \rho_{LSD,CD} & \rho_{D,CD} & \rho_{FP,CD} & \rho_{LSI,CD} & \rho_{ICV,CD} & 1 & \rho_{CD,OFI} \\ \rho_{M,OFI} & \rho_{LSD,OFI} & \rho_{D,OFI} & \rho_{FP,OFI} & \rho_{LSI,OFI} & \rho_{ICV,OFI} & \rho_{CD,OFI} & 1 \end{bmatrix} \quad (3)$$

Where ρ denotes the pair-wise correlation coefficient between the error terms in the adoption equations.

When correlations in the off-diagonal elements in the covariance matrix are nonzero, the MVP is preferred over a univariate probit or logit. The sign and significance of the correlation coefficients reveal the nature of the relationship between the adoption of adaptation equations (Kpadonou et al., 2017). Correlations can be interpreted in two ways: complementarity is indicated by a positive correlation, and substitution is indicated by a negative correlation.

Ordered probit model: Since the MVP model mentioned above only took into account the likelihood that a particular adaptation practice would be chosen and did not distinguish between, for example, individuals who adopt a single adaptation practice and those who mix numerous practices, this study applied the ordered probit model to examine factors determining the adoption decisions of the intensity of CSD practices (Kpadonou et al., 2017; Ayal et al., 2018; Teklewold et al., 2019). The study modeled the number of adaptation practices using the adopted number as the dependent variable, following Wollni et al. (2010) and Teklewold et al. (2019). The number of practices adopted may also be affected by variables affecting adoption probability. Intensity or level of adaptation strategies can be determined by the number of strategies adopted by a given household as a dependent count number, which takes a value ranging from one to eight, depending on whether a pastoral or agro-pastoral community has used one strategy or two, three, or eight. The information on the number of adaptation strategies used could have been treated as a count variable. A Poisson regression model is commonly employed to analyze count data, but it assumes that all events have the same probability of occurring (Wollni et al., 2010). In this study, however, adopting multiple strategies may not necessarily increase the likelihood of successful implementation, as these strategies may have been previously used and gained advantages. Since pastoralists' adoption of adaptation strategies is an ordinal variable, we used an ordered probit model with a category-ordered outcome (Teklewold et al., 2013; D'Souza et al., 2017).

The ordered nature of the dependent variable (Y) is a function of observed heterogeneity (X) characterized by unknown weights (β) as well as other unobserved characteristics ($\sum$) Equation (4):

$$Y_i^{*} = X_i^{'}\beta + \varepsilon_i \quad (4)$$

Where:

- Y_i^{*} is a latent (unobserved) variable that represents the propensity of the i^{th} individual to fall into a certain category of an ordered outcome.
- $X_i^{'}$ denotes the transpose of the vector, which organizes the predictors appropriately for matrix multiplication.
- X_i is a vector of independent variables (predictors) for the i^{th} observation
- β is a vector of coefficients that represents the effect of each independent variable on the latent variable Y_i^{*}
- ε_i is a random error term for the i^{th} observation, assumed to be normally distributed with a normalized mean and variance of zero and one, respectively. The relationship between the latent variable and the observed outcome is shown below Equation (5):

$$Y_i = \begin{cases} 0\ if\ Y_i^{*} \le 0 \\ 1\ if\ 0 < Y_i^{*} \le \mu_1 \\ 2\ if\ \mu_1 < Y_i^{*} \le \mu_2 \\ \ldots \\ \ldots \\ m\ if\ \mu_{m-1} \le Y_i^{*} \end{cases} \quad (5)$$

Where:

- μ is the cut point to be estimated with β for an m-alternatively ordered category, we generally define as follows:

$$Y_i = j\ if\ \mu_{j-1} < Y_i^{*} \le \mu_j,\ j = 1,2,\ldots m,$$

Where $\mu_0 = -\infty and\ \mu_m = \infty$

According to Cameron and Trivedi (2009), the probability of observing outcome j is given by:

$$\rho\left(Y_i = j\right) = \grave{e}\left(\mu_j - X_i^{'}\beta\right) - \grave{e}\left(\mu_{j-1} - X_i^{'}\beta\right),$$

Where θ is the cumulative normal distribution function of ε_i

A Problem Confrontation Index ranking was employed to assess the main barriers to the implementation of climate change adaptation. Following Gemeda et al. (2023), Popoola et al. (2020), and Masud et al. (2017), the barriers were identified and ranked using the PCI. Respondents were asked to rate their perceptions of barriers to implementing climate change adaptation strategies on a Likert scale (0–3). Accordingly, no problem = 0, low problem = 1, moderately problematic = 2, and highly problematic = 3. Hence, PCI was calculated as follows:

$$PCI = P_n^* 0 + P_l^* 1 + P_m^* 2 + P_h^* 3$$

Where PCI represents the problem confrontation index, P_n is the number of respondents who graded as having no problem, P_l is the number of respondents who graded as having a low problem, P_m is the number of respondents who graded as having a medium problem, and P_h is the number of respondents who graded as having a high problem.

2.4 Data diagnosis

Multicollinearity test: A variance inflation factor (VIF) technique has been employed to detect multicollinearity in continuous explanatory variables (Gujarati, 2004) as well as a contingency coefficient (CC) for categorical and dummy variables (S).

Calculation of the contingency coefficient for dummies and categorical variables, Supplementary Table 1:

$$CC = \frac{x^2}{1 + x^2}$$

Following Gujarati (2004), VIF was described as follows, Supplementary Table 2:

$$\mathrm{VIF}(\mathrm{Xi}) = \frac{1}{1 - \mathrm{R}^2}$$

Where R^2 is the correlation coefficient between x and the other explanatory variables. When VIF greater than or equal to 10, continuous variables are considered to be collinear (Gujarati, 2004). Dummies and categorical variables are considered collinear if their contingency coefficients are greater than 0.75.

2.4.1 Empirical specification and hypothesis testing

In addition to establishing the analytical framework, it is important to define the variables' measurements and symbols. Accordingly, the following dependent and explanatory variables are identified and described as follows.

Dependent variables: In the present study, we identified eight important adaptation strategies used, which can be grouped under livestock-based (herd mobility, livestock diversification, herd splitting, destocking, haymaking, and livestock insurance), cereal cultivation (crop diversification, improved crop variety), and off-farm livelihoods (low return income, charcoal making, and firewood selling). Based on their potential to enhance adaptive capacity and reduce vulnerability of pastoral livelihoods in the study area, these adaptation strategies were identified (Omolo, 2011; Berhanu and Beyene, 2014; Asmare et al., 2017; Tamene et al., 2023). They are expected to complement each other and create synergies to achieve the wine-wine objective, as presented below. However, in the initial run, charcoal/firewood sales and migration to town were added to the model, but they were dropped as they were not significant.

Livestock based adaptation strategy: Livestock rearing was the mainstay for the Borana pastoral communities while livestock and livestock products were the main source of livelihood in the study area. Adaptation strategies in this regard include herd mobility, livestock diversification, destocking, hay making, and livestock insurance.

Herd mobility: is one of the indigenous adaptive mechanisms that have been practiced by Borana pastoralists (Tache and Sjaastad, 2010; Berhanu and Beyene, 2015; Tamene et al., 2023). It is the movement of their herds in response to seasonal and annual changes in pastures and water availability. For pastoralists, herd mobility is not an option but an imperative practice, ranked first, without which pastoral production is impossible (Tache and Sjaastad, 2010).

Destocking: Destocking was used to reduce the number of livestock, often as a strategy to avoid loss and to manage resources during the time of drought. It aims to prevent overgrazing and degradation of rangeland, ensuring the remaining livestock can be adequately supported.

Herd diversification: Traditionally, Borana pastoralists are cattle herders because they value cattle both culturally and economically compared to other livestock species (Tache and Sjaastad, 2010; Megersa et al., 2014). Cattle are highly valued animals in social status and cultural ceremonies in the study area (Berhanu et al., 2007; Tache and Sjaastad, 2010). However, pastoral communities have started diversifying their livestock herd composition in favor of browser by adopting camels and goats in addition to cattle and sheep in response to the changing climate.

Feed preservation: Communal enclosure (kalo), preserving pasture, hay making, and feed purchase for time of adverse feed shortage were an important adaptation strategy used by Borana pastoralists. Borana rangelands increasingly adopt adaptive pastoral practices such as purchasing hay and fencing communal rangelands for fodder production and hay making (Berhanu and Beyene, 2015).

Livestock insurance: Livestock insurance is a financial instrument that helps pastoralists recover financially from livestock losses by providing a safety net against the loss of their animals as a result of climate change. It was introduced as one of the modern risk-management tools in the Borena zone of Ethiopia in 2012 by the International Livestock Research Institute (ILRI), working in partnership with Oromia Insurance Company and humanitarian agencies (Amare et al., 2019). It provides a safety net for pastoralists, allowing them to recover financially from livestock losses.

Cereal cultivation: Cereal cultivation is the most common non-pastoral adaptation strategy adopted by Borana pastoralists in the last two decades of the 20th century (Coppock, 1994; Tilahun, 1984). In the past livestock production was the sole source of livelihood for the Borana pastoralist, but in the last 10–15 years, cereal cultivation gradually expanding to the pastoral areas as economic diversification (Coppock, 1994). This dual approach allows them to diversify their livelihoods and better manage risks associated with climate variability (Berhanu et al., 2007).

Independent/explanatory variables: A total of 16 potential explanatory variables that are thought to influence and explain how pastoralists and agro-pastoralists adapt to climate change were identified and their effects studied based on literature and researchers' understanding of the context (Berhanu and Beyene,

TABLE 1 Description and summary statistics of the independent variable.

Variable	Description	Measurement	Mean	SD
Household characteristics				
Age	Age in years of the household head	Continuous	48	3.061
Gender	Gender of the household head	Dummy: 1 = Female, 0 = Male	0.88	0.327
Education	Educational status of the household head	Dummy: 1 = literate, 0 = Illiterate	1.4	0.781
DR	Dependency ratio	Continuous	0.42	0.34
Farm and resource access				
FFC	Farmers' communication	Continuous	0.23	0.18
Land size	Total land owned in ha	Continuous	1.85	0.388
TLU	Number of Livestock in TLU	Continuous	79.034	12.626
OFFA	Off-farm activity	Dummy: 1 = Yes, 0 = No	0.26	0.48
Institutional factors				
AES	Access to extension services	Dummy: 1 = Yes, 0 = No	0.32	0.17
AI	Access to climate information	Dummy: 1 = Yes, 0 = No	0.127	0.445
SI	Sources of information	Traditional = 1, modern = 2	0.127	0.446
Off-Farm	Participation in off-farm income	Dummy: 1 = Yes, 0 = No	0.14	0.34
BTBN	Bound to traditional beliefs/norms	Dummy: 1 = Yes, 0 = No	0.38	0.34
DNM	Distances to the nearby market	Continuous km	16.34	0.772
Climate-related factors				
HPT	Household perceptions of drought event	Dummy: 1 = Yes, 0 = No	0.78	0.67
HPRF	Household perceptions of erratic rainfall	Dummy: 1 = Yes, 0 = No	0.64	0.48

TLU, tropical livestock unit.

2014; Wako et al., 2017; Tolera and Senbeta, 2020; Tamene et al., 2023). Accordingly, we hypothesize that explanatory variables such as gender, education, age of the household head, family size, dependency ratio, farming activity, livestock holding (TLU), landholding, access to extension services, access to climate information, source of climate information, bound to cultural or normative belief, distance from the market, perception of temperature, and perception of rainfall variability might influence the adoption decision of communities identified (Table 1).

3 Results and discussion

3.1 Socio-economic profile of the household

Table 2 presents the demographic and socioeconomic profiles of households. Over two-thirds of households never attended any formal education, and most households were headed by males, which accounted for 88%. The adult household literacy rate was 24.7%, which is less than the national average literacy rate of Ethiopia. According to the 2017 World Bank report, the literacy rate in Ethiopia was about 52% (World Bank, 2018). Davies and Roba (2010) identified a similar problem regarding pastoralists' access to basic education. The proportion of pastoralists and agro-pastoralists having primary educational backgrounds would be an opportunity for the uptake of new development policies and adaptation strategies and is important for achieving sustainable development. The overall age of households' heads ranged from 22 to 80 years, with a mean age of 48 years, and the mean dependency ratio of the sampled households reported was 0.3.

Table 3 illustrates the major farming activities and income sources. Pastoral communities in the study area rely on both livestock and crops for their livelihoods. Livestock rearing was the dominant production and source of livelihood and food for the majority of households, while cereal cultivation was minimal and unreliable due to erratic rainfall in the study area. The major farming activities in the study area were livestock production (54.17%), followed by agro-pastoral production (45.78%) Cereal cultivation was only practiced in agro-pastoral areas. About 34.52% of respondents indicated that both livestock and cereal cultivation were their main sources of livelihood. A total of 62.5% of the sampled households were pure pastoralists, with livestock and livestock products as their primary sources of livelihood, while the rest had non-pastoral, off-farm livelihoods. Petty trade and livestock trading were also means of livelihood. The poorest segments of households in the study area rely on wage labor for income through food for work and cash for work.

3.2 Adaptation strategies and the intensities of adoption

Figure 2 depicts climate change adaptation strategies used by pastoral and agro-pastoral communities. Pastoral communities in the study area have developed and used various adaptation strategies in response to periodic droughts and irregular rainfall. These adaptation strategies included herd mobility, livestock diversification, destocking, feed preservation, livestock insurance, crop diversification, improved crop variety, and off-farm income. Herd mobility had the highest adaptation rate (81%), followed by livestock diversification (77%), feed preservation (72%), and destocking (48%), whereas rates were relatively low for livestock insurance, which was estimated at 16%.

TABLE 2 Summary statistics of household demographic and socioeconomic characteristics of Borana pastoral and agro-pastoral communities.

Variables	No	Min	Max	Mean	SD.
Age of the respondents	240	22	80	48	13.06
Dependency ratio	240	0.14	0.62	0.31	0.1
Land size	83	0.5	1.5	1.1	0.86
Livestock holding	240	5.52	862.62	79.03	121.63

Variables	240	Percent
Gender of household head		
Male	211	87.9
Female	29	12.1
Education		
Illiterate	180	75
Literate	60	25
Access to climate information		
Yes	222	92.5
No	18	17.5
Sources of climate information		
Traditional	161	75.5
Modern	61	24.5
Access to extension services		
Yes	106	44.2
No	134	55.8

Perhaps the government and development partners have not paid enough attention to the improved practices because the strategy is new for the country.

Table 4 presents the intensities of climate change adaptation strategies. Most sampled households in the study area (90%) used two or more adaptation strategies, including herd mobility, livestock diversification, destocking, feed preservation, and crop diversification. About 60% of the households used at least three or more practices, whereas 2% of them adopted a full package of adaptation strategies. Pastoral communities rarely engage in off-farm income-generating activities that could affect their income stability. This might indicate over-reliance on traditional pastoralism, which tends to limit diversification of income and livelihoods resilience. Such limited involvement in off-farm adaptation activities may subject pastoral/agro-pastoral communities to economic and environmental shock, as they would not have alternative sources of income in time of drought. Similar to our findings, Watete et al. (2016) and Mburu et al. (2017) reported that few pastoral communities engage in off-farm income generating activities, which can be attributed to a number of factors, including cultural practices, a lack of market access, and a lack of education and skills needed to transition to alternative livelihoods. The consistency of research findings across different contexts in Africa could imply that more support is needed for pastoralists to explore off-farm opportunities.

TABLE 3 Major farming activities and sources of income in Borana pastoral and agro-pastoral area.

Major farming activity	*N*	Percent
Livestock production	130	54.17
Agro-pastoral	110	45.83
Source of income		
Livestock	150	62.50
Agro-pastoral	83	34.52
Off-farm	7	2.98
Total	240	100

Source: Household survey results.

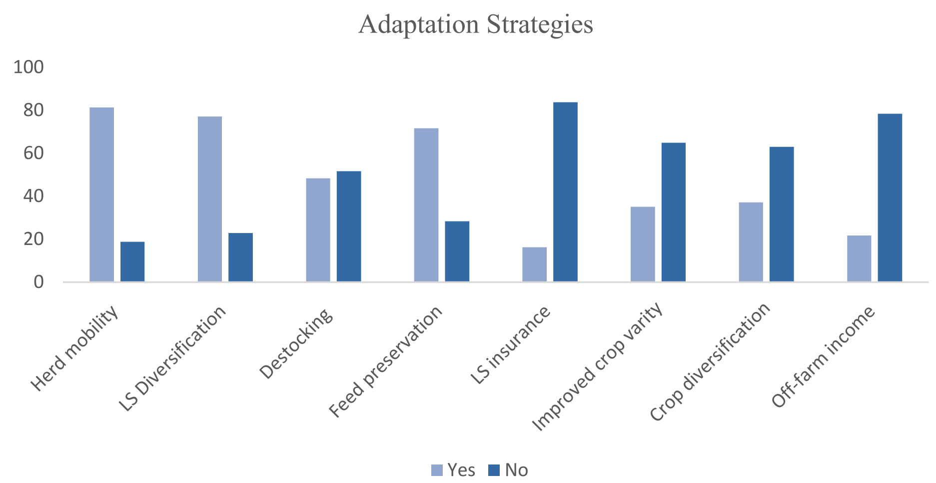


FIGURE 2
Adaptation strategies of Borana pastoral and agro-pastoral communities.

3.3 Econometric estimates

3.3.1 Interdependence of adaptation strategies

The MVP estimations are shown in Tables 5, 6. The model fits the data very well, as demonstrated by a Wald test with X^2 (120) = 191.01; p > X^2 = 0.000 (Table 6). The null hypothesis, which holds that all regression coefficients are equal to zero, is rejected. The null hypothesis that the error term covariance across equations is uncorrelated is also rejected by the likelihood ratio test, as shown in Table 5 (X^2 (28) = 180.387; p > X^2 = 0.000), making the MVP model more appropriate than a univariate probit models. The correlation coefficient of error components derived from the MVP confirms the interdependence between the adoption choices of adaptation strategies, which may be due to complementarity or substitutability in adaptation strategies but also potentially omit factors that affect all adoption decisions. As a result, pastoralists do not choose one strategy to implement; rather, the likelihood of implementing a strategy depends on the adoption of other adaptation strategies.

TABLE 4 Intensities of adaptation strategies in Borana pastoral and agro-pastoral area.

Intensity of adoption	Frequency	Percent
One adaptation strategy	24	10.00
Two adaptation strategies	32	13.33
Three adaptation strategies	46	19.15
Four adaptation strategies	42	17.50
Five adaptation strategies	40	16.65
Six adaptation strategies	36	15.00
Seven adaptation strategies	16	6.70
All adaptation strategies	4	1.67
Total	240	100.00

The sign and significance of the pairwise correlation coefficients of livestock-based adaptation strategies look consistent, suggesting that pastoralists and agro-pastoral communities used judicious combinations of practices. Herd mobility, livestock diversification, destocking, and feed preservation were positively and significantly correlated, indicating complementarity among the paired practices. This indicates that pastoral communities use a variety of livestock adaptation techniques to enhance livestock resilience and deal with recurrent drought and erratic rainfall in the study area. As described by Megersa et al. (2014) and Wako et al. (2017), livestock diversification plays an important role in enhancing pastoral adaptation capacity in the Borana lowlands. It can also be witnessed that crop-based adaptation strategies, including crop diversification and improved crop variety, have shown complementarity, indicating that farmers often combine both adaptation practices. Consistent with these findings, Mulwa et al. (2017) have reported the complementarity of improved variety and crop diversification as adaptation strategies in Malawi. In order to enhance the effectiveness of adaptation strategies among pastoral communities, policy makers and stakeholders should establish programs promoting the simultaneous implementation of livestock-based strategies, such as herd mobility, livestock diversification, destocking, and feed preservation, as well as crop-based strategies, such as crop diversification and improved crop varieties.

A significant and positive correlation was found between some of the livestock-based adaptations and crop-based adaptations. This implies that those adaptation strategies are complementary and, hence, are jointly used by the respondent households to exploit the synergy to optimize their adaptive capacity (Table 5). In contrast, livestock-based, particularly herd mobility, and crop-based adaptation strategies are negatively correlated, perhaps because crops are grown in dry-season grazing areas. The predominant private land enclosure for cereal cultivation would limit herd mobility under climate-induced shocks, thereby discourage the goal of achieving sustainable

TABLE 5 Pairwise correlation coefficients of adaptation strategies.

No	Correlation	Rho1	Rho2	Rho3	Rho4	Rho5	Rho6	Rho7	Rho8
1	Rho1	1	0.790 (0.060) *	0.088 (0.107)	0.277 (0.113) **	0.048 (0.116)	−0.108 (0.109) ***	−0.061 (0.105)	0.127 (0.105)
2	Rho2		1	0.152 (0.109)	0.169 (0.120)	0.037 (0.116)	−0.237 (0.117) **	−0.217 (0.118) ***	0.125 (0.115)
3	Rho3			1	−0.109 (0.112)	0.450 (0.096) *	−0.060 (0.109)	0.332 (0.096) **	0.275 (0.104) *
4	Rho4				1	0.446 (0.105) *	−0.158 (0.119)	0. 0.021 (0.124)	−0.015 (0.114)
5	Rho5					1	−0.396 (0.103) *	−0.125 (0.117) ***	−0.294 (0.100) *
6	Rho6						1	0.479 (0.094) *	0.275 (0.104) *
7	Rho7							1	−0.421 (0.090) *
8	Rho8								1

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho81 = rho32 = rho42 = rho52 = rho62 = rho72 = rho82 = rho43 = rho53 = rho63 = rho73 = rho83 = r ho54 = rho64 = rho74 = rho84 = rho65 = rho75 = rho85 = rho76 = rho86 = rho87 = 0; chi^2 (28) = 180.387 Prob > chi^2 = 0.0000; 1 = Herd mobility; 2 = Species diversification; 3 = Destocking; 4 = Feed purchase; 5 = Livestock insurance; 6 = Crop diversification; 7 = Improved crop variety; 8 = Off-farm income.
Significant level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

TABLE 6 Parameter estimate of multivariate probit model output.

Independent variables	Herd mobility	LSD	Destocking	Feed preservation	LS Insurance	Crop diversify	ICV	OFI
Gender	−0.05 (0.28)	−0.05 (0.03)	0.10 (0.27)	0.07 (0.25)	0.28 (0.27)	−0.3 (0.27)	0.32 (0.28)	0.2 (0.25)
Age	−0.01 (0.02)	0.01 (0.011)	0.01 (0.01)	−0.012 (0.01)	−0.01 (0.011)	0.01 (0.01)	−0.02 (0.011)	0.01 (0.01)
Education	0.02 (0.02)	0.02 (0.19)	−0.22 (0.18)	−0.01 (0.18)	0.18 (0.104) *	−0.42 (0.17) **	0.12 (0.19)	−0.01 (0.17)
Dependency ration	−0.55 (1.17)	−0.01 (0.01) **	0.34 (1.05)	−0.76 (1.02)	−0.09 (0.05) **	−0.11 (0.04) ***	1.1 (1.1)	0.73 (1.04)
Land size	−0.04 (0.11)	0.1 (0.11)	0.06 (0.09)	0.07 (0.02)	−0.38 (0.18) *	0.03 (0.09) ***	−0.18 (0.1) ***	−0.04 (0.09)
TLU	0.1 (0.06) *	0.09 (0.05) ***	0.01 (0.01) *	0.01 (0.01)	−0.01 (0.01)	−0.00 (0.001)	−0.38 (0.23) ***	0.00 (0.001)
Farming activity	−0.26 (0.24)	−0.36 (0.22)	0.15 (0.24)	0.17 (0.21)	0.02 (0.23)	0.24 (0.21)	−0.46 (0.23)	0.14 (0.20)
Bound to norm	0.17 (0.25)	−0.07 (0.24)	−0.06 (0.23)	−0.08 (0.22)	0.22 (0.23)	−0.18 (0.21)	−0.31 (0.23)	−0.25 (0.21)
Access to information	−0.39 (0.29)	0.03 (0.27) ***	0.81 (0.22) *	0.01 (0.23)	0.01 (0.24)	−0.04 (0.23)	−0.03 (0.25)	0.12 (0.23)
Sources of information	−0.21 (0.23)	0.93 (0.28) *	0.44 (0.23) ***	−0.23 (0.23)	0.02 (0.23)	−0.59 (0.23)	−0.58 (0.27) **	−0.12 (0.23)
Extension service	−0.51 (0.26) *	−0.33 (0.24)	0.34 (0.21)	−0.57 (0.21) *	−0.36 (0.22)	0.32 (0.19)	0.36 (0.21) ***	0.17 (0.2)
Distance to woreda	−0.01 (0.012)	−0.02 (0.01)	−0.01 (0.01)	0.00 (0.01)	−0.01 (0.011)	−0.01 (0.011)	−0.02 (0.012)	−0.02 (0.01) **
ERF	−0.20 (0.24)	−0.11 (0.22)	0.19 (0.21)	−0.05 (0.2)	−0.28 (0.22)	−0.28 (0.22)	0.07 (0.04) *	−0.09 (0.19)
Drought event	0.91 (0.47) *	0.07 (0.33)	−0.02 (0.31)	0.04 (0.29)	−0.14 (0.33)	−0.14 (0.33)	−0.18 (0.29)	−0.04 (0.27)

LSD, Livestock diversification; ICV, Improved crop variety; OFI, Off-farm income; ERF, Erratic rainfall; TLU, Tropical livestock unit; ERF, Erratic rain falls; TLU, Tropical livestock unit. Significant level: ***$p < 0.01$, ** $p < 0.05$, *$p < 0.1$.

livelihoods for pastoral communities. This is a contributing factor to the disruption of traditional movement between seasonal grazing areas and has contributed to conflict over land and water resources (Yirbecho et al., 2004). Therefore, it would be imperative to develop land-use frameworks that encourage coexistence between livestock grazing and crop cultivation in order to maintain ecological balance and minimize conflict.

Various low return-non-pastoral livelihoods have been adopted by pastoral households in response to climate change impacts. These off-farm non-pastoral livelihoods are positively interdependent with livestock and crop-based adaptation strategies. Multiple sources of income can greatly benefit communities that have been affected by climate change. This enables pastoral communities to adapt and overcome the loss of livestock and crop failure. Despite the fact that only a small percentage of respondents generated income from off farm activities, pastoral households adopted low-return off-farm income pursuits previously disregarded because of repeated vulnerability to climate change related shock and increasing destitution (Berhanu et al., 2007; Berhanu, 2011).

3.3.2 Determinant analysis

3.3.2.1 Determinants of adoption

Table 6 presents MVP model estimates for the factors that determine choices of climate change adaptation strategies. The results demonstrate that factors such as education, dependency ratio, TLU, farming activity, access to information, sources of information, extension services, distance to markets, and climate factors have a significant influence on the decision of adaptation strategies.

A positive and significant ($p < 0.1$) correlation was observed between household head education and livestock insurance, but a significant and negative correlation ($p < 0.1$) was observed between household head education and crop diversification. This indicates that as the level of education of the household increases, the likelihood of using livestock insurance as adaptation strategy increase. In line with the notion that education accelerates the adoption of knowledge-intensive technologies, this may be explained by the fact that education increases access to climate information and awareness of livestock insurance benefits or by the fact that they possess better access to resources that enable them to invest. Consistent with our findings, educated people tend to be less risk-averse, resulting in a higher adoption rate of strategies reported among educated household heads in previous studies (Brick and Visser, 2015; Mulwa et al., 2017; Tamene et al., 2023). On the other hand, household head education decreases crop diversification, indicating that educated household heads tend to diversify their crops less than those with lower education levels. This finding might suggest that education helps agro-pastoral communities to invest their resources in fewer, more tolerant crops or livestock.

The negative and significant correlation of dependency ratio for most adaptation strategies, with the significant effect on livestock diversification, livestock insurance, and using improved crop varieties, suggests that households with higher dependency ratios have a lower workforce to adapt and apply labor-intensive adaptation strategies. The probability of applying these adaptation strategies increases with an increasing workforce in the family. This means that, households with a lower dependency ratio have more labor available to manage these labor-intensive farming practices (livestock diversification and crop diversification), resulting in higher adoption rates. This is in agreement with previous agricultural adoption decisions by Mignouna et al. (2011), Zezza et al. (2011), and Kassie et al. (2013) and adoption decisions in dry land agro-ecology (Kpadonou et al., 2017), by suggesting the importance of active forces in the adoption process of soil and water conservation.

The number of tropical livestock units (TLU) is positively and significantly correlated with livestock-based adaptation strategies such as herd mobility, livestock diversification, and destocking but negatively correlated with the use of improved crop varieties. In other words, households with a large number of livestock are more likely to adapt to climate change than households with fewer livestock. The number of livestock sizes owned by a household is an indicator of wealth status in the pastoral area. Households with a higher TLU value can afford to take risks and rely on livestock in times of climate shock (Jones and Thornton, 2009). To this end, the prohibitively high cost of adopting drought-tolerant species, like the camel, suggests that the only households able to effectively diversify the species composition of their herd portfolios as a hedge against the current state of rising climate-induced risks of livelihood deterioration are the wealthy ones (Berhanu and Beyene, 2015). On the other hand, it is common practice for low-income and stockless households to settle for cereal cultivation or to move to peri-urban areas to find relief assistance and other non-pastoral opportunities (Berhanu and Beyene, 2015).

Climate information is positively correlated with livestock diversification and destocking, but negatively correlated with crop diversification and improved crop varieties. Accordingly, household heads who have access to climate information from traditional sources are more likely than those who have access to contemporary sources to employ livestock-based adaptation strategies and adjust to climate change. Similar to these results, Nhemachena and Hassan (2007) contend that having basic a basic understanding of climate change enhances the likelihood of adapting to it. The first step in adaptation is recognizing that the climate has changed, and then choosing and applying effective adaptation techniques (Maddison, 2007). Contrary to previous research, access to climate information was found to have a negative and significant correlation with crop-based adaptation strategies (Maru et al., 2021; Zakari et al., 2022; Gemeda et al., 2023). This suggests that households are less likely to adopt crop-based adaptation strategies when they have access to climate information.

Traditional forecasting and sources of information are the primary sources of climatic information for pastoral and agro-pastoral people. Luseno et al. (2003) provided evidence in favor of this study by demonstrating that the pastoral community uses traditional climate forecasting methods more widely than outside sources. Climate information from traditional forecasting systems was significantly correlated with herd mobility and feed preservation, but crop variety was negatively correlated, suggesting that poor pastoralists are managing climate change impacts by using traditional risk management systems. The positive correlation between climate information and herd mobility indicated that pastoralists who used traditional forecasting systems are better able to determine when to move their herds to new grazing and watering areas, in response to recurrent drought. Similarly, the information helps pastoralists and agro-pastoral in managing animal feed resources for the period of dry season or drought. On the other hand, the negative the negative correlation with crop variety could indicate that pastoralists may likely to adopt diverse cropping strategies, possibly because they prioritize livestock management over crop production.

The sign and significance of the correlation coefficient for access to extension services is consistent with that of access to climate-related information, which was negative and significant for livestock-based adaptation but positive for improved crop varieties. This suggests that access to extension services significantly increases the probability of using crop diversification and improved crop variety compared to households that have no access to extension services. This is probably because access to extension services helps households become aware of strategies and make comparative decisions among alternative adaptation practices (Gemeda et al., 2023). Contrary to this, households that have access to extension services are less likely than those who do not to use adaptation techniques for feed preservation and herd mobility. The partial inefficiency of extension services in livestock-based adaptation strategies might be because the extension service given is not development-oriented. The FGD participants indicated that rather than providing useful development advice, a substantial portion of extension contact is devoted to tax collection and local political and security issues. According to these results, extension services are largely less development-oriented, except for a health program in the study region (Berhanu and Beyene, 2014).

Market access has a negative effect on both livestock and crop-based adaptation strategies as well as off-farm income-generating activities in the face of climate change. Proximity to the local market influences the uptake of adaptation strategies by pastoral communities because it facilitates information exchange and makes buying and selling activities easier. In agreement with our findings, previous studies by Maddison (2007) suggest that the absence of markets hinders farmers' adaptation to change among livestock producers. Agricultural technology adoption findings indicate that market access has been shown to increase the ability of farmers to adopt CSA practices by lowering transaction costs, facilitating the transportation of inputs and outputs, saving opportunity costs associated with time, and making it easier to obtain timely information about production, markets, and climate (Aryal et al., 2018; Maindi et al., 2020).

Drought events and erratic rainfall had significant ($p < 0.1$) effects on households using improved crop varieties and herd mobility, implying that having a perception of drought events and erratic rainfall would increase the likelihood of households being involved in using improved crop varieties and herd mobility. From the estimated relationship, one would expect that herd mobility increases significantly during drought events, which is consistent with the expected result. Pastoralists separated their herds into smaller groups and relocated them to several grazing places at the same time in order to deal with resource patchiness during drought situations. In addition, the erratic nature of rainfall had a significant effect on households' choice to use improved varieties as adaptation strategies, implying that if households perceive a change in rainfall pattern, they are more likely to use improved crop varieties to minimize the effects of climate change. According to interviews with key informants, agro-pastoral communities use drought-resistant crops and early-maturing varieties as adaptation strategies. However, the negative correlation between drought events, erratic rainfall, and other adaptation strategies is inconsistent with our prior expectations and existing literature (Debela et al., 2015; Gemeda et al., 2023).

3.3.2.2 Determinants of the intensity of adoption

Pastoral communities used diverse adaptation strategies to enhance climate resilience in the study area due to their

TABLE 7 Parameter estimates of ordered probit model out.

Variables	Marginal effects								
	Coefficient	Pr(Y = 1/X)	Pr(Y = 2/X)	Pr(Y = 3/X)	Pr(Y = 4/X)	Pr(Y = 5/X)	Pr(Y = 6/X)	Pr(Y = 7/X)	Pr(Y = 8/X)
Age	0.015 (0.012)	−0.001 (0.001)	−0.002 (0.000)	−0.002 (0.002)	−0.002 (0.002)	0.001 (0.000)	0.002 (0.020)	0.001 (0.001)	0.001 (0.001)
Gender	0.242 (0.319)	−0.011 (0.017)	−0.005 (0.000)	−0.034 (0.044)	−0.031 (0.040)	0.016 (0.023)	0.030 (0.04)	0.022 (0.030)	0.012 (0.017)
Education	−0.302 (0.182)	(0.015) (0.012)	0.006 (0.006)	0.042 (0.027)	0.038 (0.024)	−0.020 (0.016)	−0.037 (0.023)	−0.027 (0.019)	−0.015 (0.012)
Dependency ration	−0.155 (0.059) *	−0.076 (0.069)	0.029 (0.035)	−0.217 (0.08) **	0.197 (0.144)	−0.011 (0.006) *	−0.019 (0.008) **	−0.142 (0.007) **	−0.078 (0.069)
Land size	−0.106 (0.125)	−0.005 (0.007)	0.003 (0.003)	0.022 (0.009) **	−0.013 (0.016)	−0.007 (0.009)	−0.013 (0.016)	−0.010 (0.012)	−0.005 (0.007)
TLU	0.001 (0.002)	−0.001 (0.000)	−0.000 (0.000)	−0.006 (0.001)	0.020 (0.008) **	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Source of inf.	−0.108 (0.25)	0.005 (0.013)	0.002 (0.005)	0.015 (0.034)	0.014 (0.032)	−0.007 (0.017)	−0.013 (0.031)	−0.010 (0.023)	−0.005 (0.013)
Farming Act	0.491 (0.287) ***	−0.024 (0.019)	−0.009 (0.010)	−0.068 (0.042) ***	−0.062 (0.036) ***	0.033 (0.025)	−0.013 (0.037)	0.045 (0.029)	0.025 (0.019)
Bound to Norm	0.081 (0.263)	−0.004 (0.013)	−0.002 (0.005)	−0.011 (0.037)	−0.010 (0.033)	−0.006 (0.018)	−0.019 (0.008) **	0.007 (0.024)	0.004 (0.014)
Assess to extension	−0.168 (0.251) *	0.008 (0.013)	0.003 (0.006)	0.023 (0.035)	0.021 (0.032)	0.011 (0.018)	−0.021 (0.031)	−0.015 (0.023)	−0.008 (0.013)
Access to inform	0.181 (0.263)	−0.010 (0.014)	−0.003 (0.006)	−0.025 (0.037)	−0.023 (0.033)	−0.012 (0 0.019)	0.022 (0.033) **	0.017 (0.025)	0.009 (0.014)
Distance to district	−0.031 (0.012) *	0.002 (0.001)	0.001 (0.001)	0.004 (0.002) **	0.003 (0.002) **	−0.020 (0.01) *	−0.004 (0.002)	−0.003 (0.010)	−0.002 (0.001)
Drought event	−0.219 (0.261)	−0.011 (0.014)	0.004 (0.006)	0.030 (0.037)	0.028 (0.033)	−0.015 (0.019)	−0.027 (0.033) ***	−0.020 (0.025)	−0.011 (0.014)
ERF	0.757 (0.410)	−0.037 (0.029)	−0.014 (0.016)	−0.105 (0.06) ***	−0.095 (0.053) ***	0.050 (0.038)	0.093 (0.052)	0.070 (0.042) ***	0.030 0.029
μ_1	−2.864 (1.201)								
μ_2	−1.669 (1.192)								
μ_3	−1.774 (1.164)								
μ_4	−0.982 (1.156)								
μ_5	0.254 (1.163)								
μ_6	0.923 (1.163)								
μ_7	1.164 (1.175)								

Log likelihood = −157.24837; Wald chi^2 (15) = 23.15; Prob > chi^2 = 0.0000; Pseudo R^2 = 0.0686; μ represent cut points; Values in the brackets are standard errors. Significant level: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. FTF = Farmers to farmers communication; Culture = Bound to culture/norm; ERF = Erratic rain falls.

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TABLE 8 Barriers to climate change adaptation strategies in Borana pastoral and agro-pastoral areas.

Adaptation barriers	Degree of barriers				PCI	Rank
	No problem	Low	Moderate	Highly		
Bush encroachment	27	24	44	145	547	1
Inappropriate settlement pattern	30	35	50	125	510	2
Regionalization policy	33	30	82	95	479	3
Devaluating traditional knowledge	27	34	97	82	474	4
Lack of technical knowledge	49	30	48	113	465	5
Expansion of farmland	29	47	95	69	444	6
Market problem	51	47	35	107	438	7
Impotency of traditional leaders	42	48	85	65	413	8
Inappropriate Dev't intervention	40	59	88	53	394	9

complementary characteristics. Previous studies indicated that the integration of multiple adaptation strategies leads to multiple benefits, such as enhancing adaptive capacity, reducing households' vulnerability and food insecurity, and rehabilitating ecosystem goods and services (Kpadonou et al., 2017; Mulwa et al., 2017). Table 7 presents the estimated coefficients and marginal effects of the independent variables on each outcome of the dependent variables.

The coefficient for the dependency ratio was negative, suggesting that households with a low dependency ratio are more likely to intensify the use of adaptation strategies against climate calamities than households with a high dependency ratio. This result is consistent with the assumption that pastoral and agro-pastoral communities that have an active workforce in the family can adopt and exercise various adaptation strategies simultaneously. Our findings confirm the labor-intensive nature of the adoption of adaptation strategies. In contrast to these results, Kpadonou et al. (2017) emphasize the importance of young children in the adoption process of soil and water conservation in West African dry lands. The results also showed a significant positive impact of farming activities on the intensity of adoption, implying that agro-pastoral communities were more likely to intensify the use of different adaptation strategies than pastoral livelihoods. Access to extension services and distance to the nearest market, however, significantly affected the intensity of adaptation strategies. These results are consistent with those reported in the previous section and stress the role of extension services in the adoption decision of intensities of adaptation. These findings suggest that having access to extension services decreases the likelihood of using more adaptation strategies. Walking distances to the nearest market are also important in determining pastoral and agro-pastoral communities' decisions towards the intensive use of adaptation strategies, implying that the intensity of adaptation strategies was significantly influenced by market access.

The marginal effects, as can be seen in Table 7, show three major figures. For the first instance, the sign of the coefficient is inconsistent with the marginal effects, especially their signs, which differ from most coefficients. For most of the marginal effects, $Y \leq 5$, which is livestock-based adaptation strategies, agrees with the coefficient with regards to either signs or their significance. For $Y \geq 6$, crop-based and off-farm adaptation strategies agree with the coefficient about their signs. The marginal effects for $Y \leq 5$ and $Y \geq 6$ are quite opposite, either in terms of signs or significance. This highlights the differing impacts of livestock-based versus crop-based and off-farm strategies on the overall adaptation outcomes. The result may indicate that the characteristics of pastoral and agro-pastoral communities that adopt many adaptation strategies are different from those that adopt very few adaptation practices (Kpadonou et al., 2017). The latter group may consist of agro-pastoral communities that apply both livestock and cereal cultivation, whereas the former may consist of pastoral communities that solely depend on livestock production for adaptation strategies. The estimated coefficients of the ordered probit model and the related implications discussed above better fit the features of households that adopt more than two practices. For households that adopt very few practices, specific measures are required to up-scale the adoption rate and intensity of the use of adaptation strategies among them. Consequently, understanding these nuances is essential for tailoring effective adaptation measures in response to varying conditions.

3.4 Barriers to adaptation to climate change

The major limiting factors that affect pastoralists' and agro-pastoralists' adaptation to climate change and variability are bush encroachment, inappropriate settlement patterns, regionalization policies, devaluing indigenous knowledge systems, and a lack of knowledge. As indicated in Table 8, bush encroachment, inappropriate settlement patterns, and regionalization policies were the top three and most important barriers to adaptation to climate change and variability in the study areas. The study by Gemeda et al. (2023) in Ethiopia, Simotwo et al. (2018) in Kenya, and Nkuba et al. (2020) in Uganda identified that high costs of farm inputs and inadequate or no access to extension services were the major barriers to adaptation strategies, respectively. According to focus groups and key informant interviews, bush and invasive plant species encroachment was one of the observed indicators of climate change. In the past few decades, previous studies have shown that the Borana lowland had some of the best rangelands in East Africa (Angassa et al., 2006). According to respondents, the rangeland is deteriorating and dominated by thorny plant species that are not edible for livestock. Other factors like inappropriate settlement, the regionalization policy of the Ethiopian government, imposing modern institutions on customary ones, expansion of farmlands, lack of knowledge, and market problems are among the barriers that were identified during the fieldwork.

Borana pastoral communities have indigenous knowledge which enable them to have deep understanding of their ecosystems, including forecasting seasonal variations and resource availability, natural resource management and use, and traditional risk management practices. As stated by Birch and Grahn (2007), Pastoral adaptations and climate-induced innovative coping mechanisms are strategically embedded in the indigenous social structures and resource management value systems. Devaluing this indigenous knowledge can weaken their resilience to climate changes, as they may not use traditional strategies that efficiently mitigate shock. When indigenous knowledge is undervalued, the voices of local leaders are relegated in decision-making processes. This can result in the implementation of external policies that may not reflect local realities, further obscuring adaptation efforts. Bush encroachment reduces the availability of livestock feed, thereby reduce animal productivity, which is crucial for pastoralists' livelihood. It can lead to a decrease in biodiversity, as invasive plant species outcompete native grasses and shrubs.

Land enclosure for cereal crops, inappropriate settlement patterns, and regionalization policies restrict herd mobility and trigger conflict between neighbors. This condition may result in increased tension and competition for resources in local communities. Pastoralists' livelihoods may be jeopardized if they are unable to sustain their herds due to restricted access to rangeland. This could worsen already-existing conflicts and obstruct regional collaboration and development projects. In line with the present results, Tache and Sjaastad (2010) documented that the expansion of farmlands and the regionalization policy of Ethiopia have curtailed community access to pasture land and further constrained local adaptation strategies like herd mobility, which is considered to be a response to climate change and variability impacts. In addition, Oba (2011) explained that "loss of herd mobility implies that the indigenous system of land use is no longer sufficiently responsive to ecological and climatic variability." These disputes can be mitigated by putting laws into place that support equitable land usage and offer substitute grazing options. Cooperation and understanding can be promoted by supporting community-based land management projects and promoting communication between neighbors to reduce trans-regional conflicts. Additionally, pastoralists and agro-pastoralists can benefit from investments in infrastructure development and sustainable farming methods, which will lessen resources coemption.

4 Conclusion

The impacts of climate change on agriculture are a common challenge, particularly for pastoral and agro-pastoral communities whose livelihoods heavily depend on natural factors. Pastoral and agro-pastoral communities in the lowlands of Ethiopia have been using different adaptation strategies for a century to avert the impacts of climate change. The present study analyzed determinants of pastoralists' and agro-pastoralists' adaptation choices to climate change and barriers to adaptation strategies in Borana, southern Ethiopia. We applied a joint analysis framework combining both multivariate and ordered probit models to analyze factors affecting the adoption decisions of adaptation strategies and intensity of adoption, and problem confrontation index for barriers to adaptation. This enabled us to provide a more thorough understanding of the challenges surrounding the adoption of these adaptation strategies. The results indicate that while there are various adaptation strategies, some of them have very low adoption rates. Livestock insurance, for instance, is a recently developed adaptation strategy with a poor adaptation rate in the study area. The concerned body should focus on the adaptation strategies that have a low adoption rate and should take the necessary measures to promote their implementation. Similarly, the intensity of adoption for these adaptation strategies is also very low. About 50% of the households used only one to four adaptation strategies, which implies that important potential still exists to improve adoption rates of specific adaptations as well as the intensity of adaptation strategies.

The empirical result also showed that many adaptation strategies are interdependent, which means that some are complementary and others are substitutable. It appears that promoting each practice as part of a package that includes related practices may help increase the uptake of adaptation strategies while utilizing their synergies to enhance resilience to climate change impacts. Education, dependency ratio, farming activity, access to extension services, distance to market, and climate variables influence the adoption and intensification of adaptation strategies. Bush encroachment, inappropriate settlement patterns, regionalization policy, and the expansion of farmland are among the most important barriers hindering the implementation of climate change adaptation. Hence, interventions that facilitate factors determining the decision to adopt climate change adaptation strategies and address barriers to their implementation may enhance pastoral and agro-pastoral ability to adapt to the changing climate. Stakeholders and policy makers should encourage programs that promote the simultaneous implementation of livestock-based strategies and crop based to enhance the effectiveness of adaptation strategies among the pastoral communities. It would be also imperative to develop land-use planning that encourages coexistence between livestock grazing and crop cultivation in order to maintain ecological balance and minimize conflict.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The ethical approval for the present study was obtained from Salale University Ethical Committee. To obtain consent, the respondents were informed about the study and the information is used only for the intended purpose prior to interview, and data generated by a participant was kept confidential, and all informants were acknowledged.

Author contributions

AF: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. AA: Conceptualization, Data curation, Investigation, Project administration, Supervision, Validation, Visualization, Writing – review & editing. MT: Investigation, Resources, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2025.1545422/full#supplementary-material

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