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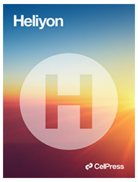

Research article

Knowledge of climate change and adaptation by smallholder farmers: evidence from southern Ethiopia

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ABSTRACT

Climate change has the greatest negative impact on low-income countries, which burdens agricultural systems. Climate change and extreme weather events have caused Ethiopia's agricultural production to decline and exacerbated food insecurity over the last few decades. This study investigates whether farmers' awareness and perceptions of climate change play a role in climate change adaptation using climate-smart agricultural practices. To collect data, 385 households in Southern Ethiopia were sampled using a multistage sampling. A Heckman probit two-stage selection model was applied to investigate the factors influencing farmers' perceptions to climate change and adaptation measures through adoption of climate-smart agriculture practices, complemented with key informant interviews and focused group discussions. The results indicated that most farmers (81.80%) perceived that the local climate is changing, with 71.9% reporting increased temperature and 53.15% reporting decreasing rainfall distribution. Therefore, farmers attempted to apply some adaptation practices, including soil and water conservation with biological measures, improved crop varieties, agroforestry, improved breeds, cut and carry system, controlled grazing, and residue incorporation. The empirical results revealed that farmers adaptation to climate change through adoptions of CSA practices was significantly influenced by education, family size, gender, landholding size, farming experience, access to climate information, training received, social membership, livestock ownership, farm income and extension services. The study found that farmers' perceptions of climate change and variability were significantly influenced by their age, level of education, farming experience, and access to climate information, hence, the need to focus on enhancing the accuracy of weather information, strengthening extension services, and considering a gender-sensitive adaptation approach toward improving farmers' knowledge and aspirations. Agricultural policies should support the efforts of farmers to increase the reliance on climate risk and alleviate farmers' difficulties in adopting climate-smart agriculture practices.

1. Introduction

Climate change and variability remain the major challenges facing humanity globally (Abdallah et al., 2019; Hundera et al., 2019; Pedersen et al., 2021). Climate change poses a serious threat to developing countries where most of their population depends on climate-sensitive livelihoods with poor adaptive capacity (Asfaw et al., 2021). For instance, the Fifth Assessment Report of the IPCC's Working Group II (Edenhofer, 2015) indicated that the impacts of climate change are expected to worsen the existing poverty in most low-income countries. This especially applies to rural Africa, where millions of people are suffering from hunger and food insecurity (Sasson, 2012). According to the recent reports, climate change has already negatively impacted sub-Sahara African agriculture and food security (Njeru et al., 2016; von Braun, 2020). The overreliance on rain-fed agriculture makes Africa's agricultural system highly vulnerable to climate change (Antwi-Agyei and Stringer, 2021). Climate change is associated with low agricultural productivity, food insecurity, job losses, natural resource depletion and increased

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resource use conflicts (Alewoye et al., 2020; Pedersen et al., 2021; Tsegaye et al., 2017; Etana et al., 2020; von Braun, 2020).

Extreme weather events and climate variability have reduced agricultural production in Ethiopia and contributed to food insecurity (Hilemelekot et al., 2021), displacement (Solomon et al., 2018), poverty (Onyutha, 2019; Seife, 2021), and increasing conflicts (van Weezel, 2019). Agriculture is the mainstay of the Ethiopian economy and contributes 52% of gross domestic product (GDP) and 80% of total employment, and generates 80.2% of the foreign exchange earnings; hence, it is the primary sector contributing to income and food security (Belay et al., 2021; Deressa et al., 2011). The country's agricultural sector is dominated by small-scale mixed crops and low-level livestock productivity while experiencing poor extension services (Tessema and Simane, 2021). The main factors influencing the low productivity of the agriculture sector in Ethiopia include traditional agricultural practices, severe land degradation caused by deforestation and overgrazing, poor institutional services (e.g., extension, credit services, and marketing), and climatic extremes, such as drought and flooding (Deressa et al., 2011; Etana et al., 2020; Tesfahunegn and Gebru, 2021). Those factors weaken and negatively affect the adaptive capacity of smallholder farmers to climate change (Jha and Gupta, 2021).

Recent studies conducted in Africa, including Ethiopia, indicate that climate change causes crop yield reduction and food insecurity. For instance, Kogo et al. (2021) highlighted that current climate change and future projections continue to negatively affect agricultural production, thus causing food insecurity and alter cropping patterns in Kenya. Ojara et al. (2021) indicated that climate change will affect corn production in Tanzania negatively. Moreover, Austin et al. (2020) have shown that climate change is likely to worsen Rwandan agricultural production. Thus, understanding the severity of the impacts and adaptation investment in the agriculture sector is imperative. Tachie-Obeng et al. (2013) reported the significant impact of climate change on Ghana 's agriculture production; thus, the adoption of improved agricultural technologies with sound policy support is crucial.

Recent studies conducted in Ethiopia showed that extreme weather events had a significant impact on agriculture, with the country's economic performance falling by 9% between 1991 and 2010 (Feyissa et al., 2018; Gemeda et al., 2021; Wordofa et al., 2021). Moreover, Benti & Abara (2019) reported that 10% of national GDP has declined from its proposed target, and Zewdu et al. (2020) projected that the national GDP will decline from 6% to 32.5% with in the period between 2030 and 2050. A recent study by Gemeda et al. (2021) indicated that rainfall fluctuations like late or early rainfall patterns and poor rainfall distribution significantly impacted crop performance. In addition, temperature variability has also created a conducive environment for pests and diseases by maximizing pathogens' reproduction and survival lifecycle (Ebi et al., 2019). Furthermore, studies have demonstrated that the spatial extent and coverage of extreme floods and droughts will continue in the future (Mase et al., 2017; Siderius et al., 2021; Tegegne and Melesse, 2021).

Farmers' knowledge of climate change and variability increases their access to climate information and influences their adaptation plans (Ricart et al., 2019). Farmers have different perspectives on climate change when compared with the scientific community. That is to say, scientists frame climate change in distinct ways, whereas farmers rely on their social values, interactions with local communities, and constructs of climate change knowledge and understanding to adapt to climate change (Nguyen et al., 2019). Consequently, farmers' understanding, and perception of climate change are primarily shaped by their personal views, with a limited scientific basis (Hundera et al., 2019). Recent literature indicated that personal opinion and public perception of climate change remain to be the critical gaps in the subjective measure of climate change, and this needs to be addressed through scientific evidence (Howe et al., 2019; Ringler et al., 2010; Silvestri et al., 2012).

Some studies have attempted to assess farmers' awareness of climate change/variability and its impacts on agriculture in Ethiopia (Belay et al., 2017; Below et al., 2015; Etana et al., 2021; Mekonnen et al., 2021; Mekuyie and Mulu, 2021; Thinda et al., 2021; Zerssa et al., 2021). On the one hand, it has been reported that most farmers have noticed a change in climate (Weldegebriel and Prowse, 2017). For example, Etana et al.(2021) explored the effectiveness of climate change adaptation (CCA) on income and food security improvement in Ethiopia. The authors reported that farmers have a better understanding of climate change. However, the findings focus on understanding of climate change from the farmers' perspective, and this was not triangulated with observed meteorological data. On the other hand, a few studies claimed that farmers lack knowledge (Ali et al., 2021; Asrat and Simane, 2017) and perceptions toward climate change (Esayas et al., 2019; Etana et al., 2020). Talanow et al. (2021) argued that farmers' level of perception of climate change determines their decisions to implement adaptation measures. Adaptation is the local response to climate stimuli, which address the critical gaps, that is, farmers' perceptions and knowledge of the changing climate (Ricart et al., 2019). Therefore, there is mixed evidence concerning farmers' understanding and awareness of climate change and variability (Abrha, 2015; Ali, 2021; Sertse et al., 2021). This mixed evidence might have resulted from the different contexts in which the studies were conducted. Therefore, research in the rural Ethiopian context is necessary in order to understand farmers' knowledge and perceptions of climate change.

This study aims to examine how farmers' knowledge and perceptions determine CSA adoption as an adaptation measure in dealing with climate change and variability in Southern Ethiopia. Some scholars hypothesized that perception comes before any adaptation interventions taken in response to changing climate and variability (Bradley et al., 2020; Singh et al., 2017). Farmers' decision-making process on adoption of improved agriculture practices requires more than a single step and the Heckman probit sample selection model with two step procedure was employed to address the selection bias (Heckman, 1976). Several studies have adopted similar technique to deal with potential selection bias involved. For example, McBride and Daberkow (2003) employed two step regression model to investigate the factors affecting farmers' awareness to climate change in the first step and adoption of new agriculture measures in the second step. Maddison (2006) and Morton (2007) also argued that adaptation to climate change needs two step process that involves perceiving to climate is change and then take measures through appropriate adaptation strategies to respond to the perceived change. Maddison (2006) employed the two-step procedure to address climate change adaptation in Africa at wider level. However, the results were aggregated and provide less contribution to address the country or local specific case of farmers' perception and adaptation to climate change and variability.

This study complements existing studies on climate change perception and adaption in two ways. First, it uses Heckman probit sample selection model two step procedure to correct the selection bias during decision making process (Heckman, 1976). Second, this study rigorously examines the factors that determine climate change perceptions in the first stage and adaptation measures through CSA adoption under changing climate. Thus, the findings of this study contribute to a deeper understanding of how farmers' perceptions guided the adoption of CSA in Southern Ethiopia and enhanced the implementation of climate action policies in Ethiopia. The remainder of this paper is organized as follows: background of the study, conceptual framework, methods, results, and discussion, and conclusions and policy implications.

1.1. Conceptual framework

Recent literature revealed that climate change perception is a challenging process that involves psychological concepts, such as attitudes, beliefs, and concerns on how climate change is happening (Fierros-González and Lopez-Feldman, 2021). Perception, in this case, refers to people's understanding of the reality and causes of climate change, its consequences, and the factors that determine the decision to apply appropriate measures (van Valkengoed et al., 2021).

The literature shows that a variety of factors play a role in influencing perceptions. For instance, Foguesatto and Machado (2021) indicated that age, income, farm size, and weather information from mass media and the internet influence Brazillian farmers' perceptions. Similarly, Tesfahunegn & Gebru (2021) showed that farmers' perceptions of climate change can be influenced by biophysical and institutional factors. In addition, personal experience (self-reported) is important in shaping the perception of climate change and potentially reducing its perceived psychological barrier from different perspectives (Howe et al., 2019; Sambrook et al., 2021). Sambrook et al. (2021) argued that people might process new information that potentially shapes their perception in a biased way and generate a conclusion to maintain their prior beliefs or experience.

Farmers' perceptions can be shaped by individual characteristics, life experience, information received from different sources, weather events, and demographic and sociocultural conditions (Whitmarsh and Capstick, 2018). Their understanding and knowledge of climate change are captured through perceptions and awareness of climate change. Therefore, measuring the climate perception of farmers and their adoption process needs to be articulated and supported by perception theories. In this regard, different theories of perception have been developed to understand farmers' perceptions and awareness of climate change. This present study employed the theory of planned behavior (TPB) to conceptualize rural farmers' perception and behavioral control over the current climate change and variability. This theory has been used in past studies (Ajzen, 1991; Hyland et al., 2016; Jethi et al., 2016; Morton, 2007; Owusu et al., 2017; Rogers, 2004; Teklewold et al., 2019; Wheeler et al., 2013). TPB was analyzed from three aspects: (1) attitudes toward behavior, subjective norm, and perceived behavioral controls; (2) linked to farmers' cognition of climate change perceptions; and (3) aspiration of CSA adoptions. Aspiration is the reference point for farmers to achieve the target of desire that improves the farming system by adopting CSA practices. Farmers are motivated to achieve their targets of improving agricultural production for bettering their lives against climate change risks (Duan et al., 2021). Farmers' aspirations in agricultural production are based on, for example, aspiration window, gap, capacity, and failure (Nandi and Nedumaran, 2021). The aspiration window denotes that the farmers' cognitive dimension draws aspiration in their domain. Meanwhile, the aspiration gap is what farmers aspire to and what they can achieve, whereby such gaps affect their future. According to Janzen et al. (2017), farmers who have high aspirations and internal locus of control are forward-looking and tend to benefit their families and communities' resilience toward climate shocks. Farmers' perception of climate change and their decision to take CSA measures is associated with the internal locus of control and their aspiration (Knapp et al., 2021). Climate extremes become more frequent and intense thus, smallholder farmers feel the impacts and contemplate their future, leading to aspiration failure and cognitive depression.

Rogers's (2004) theory of diffusion summarizes the main factors influencing farmers' aspirations and decisions over their CSA adoption process. Such factors include the innovator who takes the risk of using new farming technologies, the ways of information dissemination for early adopters, the time conditions that early majority was convinced for CSA adoption, the skeptical characteristics of farmers who seek to see evidence of adoption benefits, and the poor farmers who are suspicious of new farming technologies. The theory assumes that farmers' adoption decisions are influenced by their willingness to change, information content, and access.

However, previous studies showed many factors affecting farmers' adoption of agricultural innovation. For instance, Wheeler et al. (2013) asserted that farmers who perceived behavioral controls should consider different factors, such as social, biophysical, economic, human, institutional, demographic, and farm characteristics. Meanwhile, Owusu et al. (2017) and Jethi et al. (2016) also stated that climate and non-climactic factors determine the performance of farmers toward their agricultural productivity. Previous studies have documented the adaptation to climate change that mainly depended on farmers' perceptions and awareness of the change, institutional support, and clear agricultural policy directions. According to Li et al. (2021), Mirzabaev (2018), and Morton (2007), the adaptation to climate change follows a two-step process: the initial step requires farmers to perceive that climate is changing, and the next step requires taking adaptation measures. Teklewold et al. (2019) and Fierros-González and Lopez-Feldman (2021) stated farmers' perceptions and expectations of climate variability as the crucial prerequisite for improved farming practices, such as the adoption of CSA practices and technologies.

Understanding farmers' perception can be considered a precondition for designing and successfully implementing the selected agricultural innovations (Carlos et al., 2020). Effective implementation of such intervention requires proper institutional arrangements and clear policy directions that enhance the CSA adoption and its effectiveness among rural farmers. Hellin et al. (2021) suggested that CSA practices must bring farmers, researchers, policymakers, and relevant stakeholders together and investigate the existing practices and new technologies in response to current climate variability and change. This study focuses on farmers' knowledge and perception of climate change/variability and its impacts over the last three decades. Farmers have a mixed understanding of climate change; some farmers perceived, whereas others do not. Farmers' decision to use CCA is determined by their understanding and perception of climate change and variability. However, farmers' response to adaptation decisions may be driven by internal and external factors (e.g., education, farming experience, household size, landholding size, livestock ownership institutional services, social network, and market infrastructure). These factors could be a constraint for farmers to participate in the adaptation process (Below et al., 2015).

Accordingly, farmers' knowledge and perception of CCA focus on rainfall and temperature change over the past three decades. Some farmers could have perceived climate change and others do not. Similarly, not all farmers take improved adaptation measures, and farmers' response to climate change is influenced by external and internal factors which determine their adoption ability. In this regard, examining farmers' perception of climate change and their adaption intentions by integrating socioeconomic and biophysical factors need to be explored. This would contribute to more social desirability and networking, access to valuable climate information, and improved knowledge and understanding of farmers' adaptation behavior. Farmers' CCA requires sound policy support and facilitates farmers' decisions to adopt improved agricultural practices and enhance the adaptation capacity of the households. Adaptation constraints (e.g., lack of knowledge, limited input supply, poor institutional support, aspiration failure, and money shortage) provide potential entry points for CSA adaptation policymaking and its implementation. Figure 1 illustrates the conceptual framework of farmers' perception and adaptation behavior used in this study (von Braun and Birner, 2017). Therefore, the conceptual framework illustrates how farmers' knowledge and perception of climate variability contribute to the adoption of appropriate adaptation strategies to overcome the negative impacts of climate change.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Doyogena District (7°17′–7°19′ N latitude and 37°45–37°47 E longitude), which is located in the Southern region of Ethiopia (Figure 2). The altitudinal range in the area varies between 2,420 and 2,740 m above sea level. The annual mean temperature ranges from 12 °C to 20 °C, and the mean annual rainfall ranges 972–1023 mm (Belay et al., 2021). The study area experiences two rainfall seasons, namely, *Kiremt* (from June to September) and the short rainy season *Belg* (from March to May) (Belay et al., 2021). Farmers in the area practice mixed-agriculture (crop-livestock) farming system with legumes, cereals, fruit trees, and vegetable root crops; perennial crops, such as *Enset* (Ensete

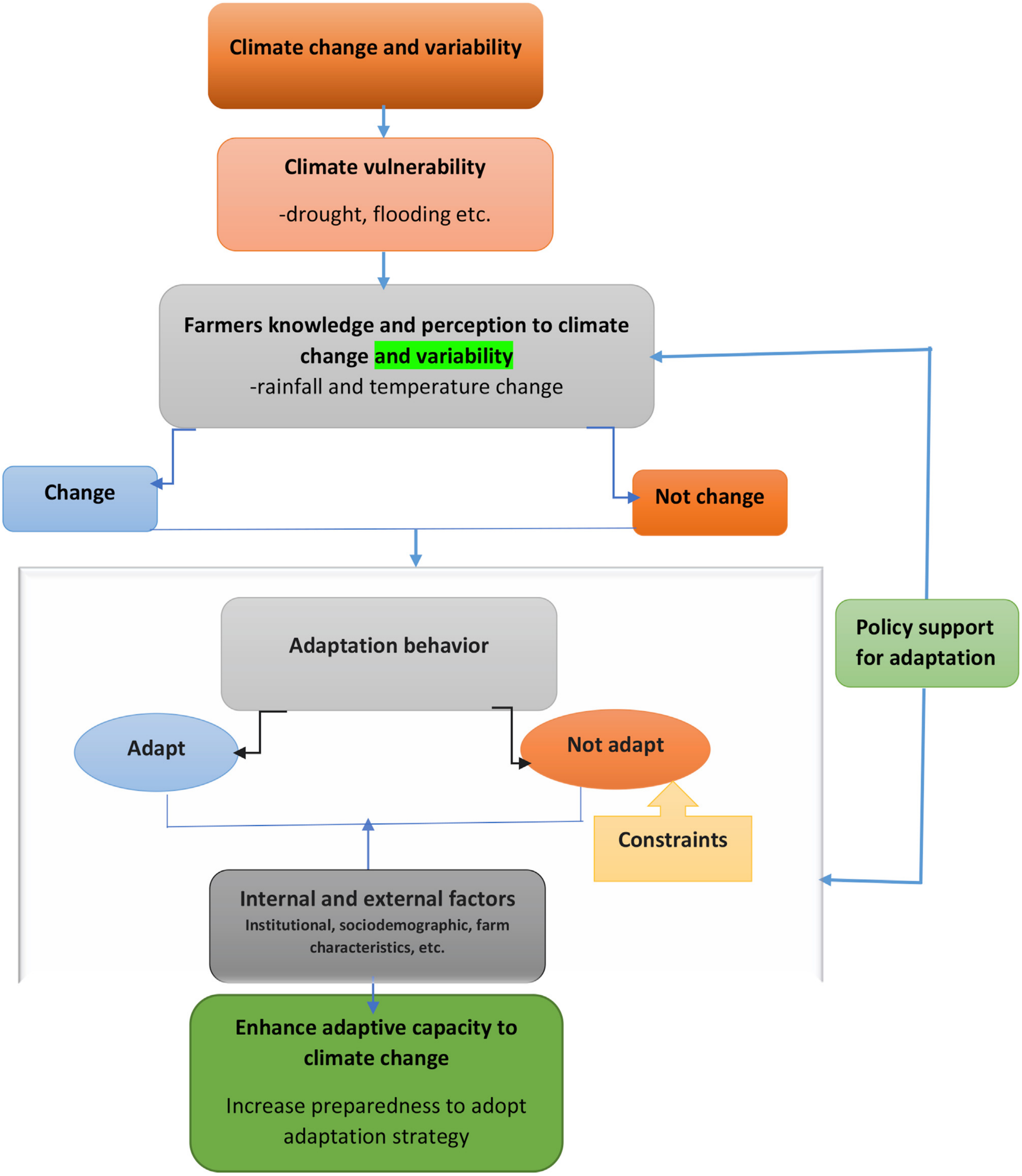

Figure 1. Conceptual framework adapted from Abidoye and Odusola (2015), Hyland et al. (2016), Morton (2007), Wheeler et al. (2013), and Arunrat et al. (2017).

ventricosum) (Tadesse et al., 2021). *Enset* is the common drought-tolerant and multifunctional crop-producing high calorific value of food called "*Kocho*," which is the typical staple food for all communities. The area is vulnerable to climate and non-climate-related risks, including increased rainfall variability, declining soil fertility, water inaccessibility, fragile soils, free grazing, soil erosion, land fragmentation, feed shortage, livestock diseases, deforestation, and soil degradation (Findji et al., 2020; Tadesse et al., 2021; Taye et al., 2016). The study sites have a heterogeneous highlands landscape with diverse crop-livestock farming systems. Moreover, the ethnographic situation of the area indicates that different ethnic groups (e.g., Kembata, Hadiya, Wolaita, Tembaro, Gedio, and Guragie Halaba) are living together, settling under different villages, and sharing values, cultures, religions, and food systems (Melketo et al., 2020). The farmers have scattered nature of settlement with mostly cultivated agricultural land use type. Following the demographic growth and parceling out of the farm plot, most existing settlements established at the top of the hills are ideally suitable for growing different crops. Communities have a common social asset called "*Iddir,*" which is a traditional

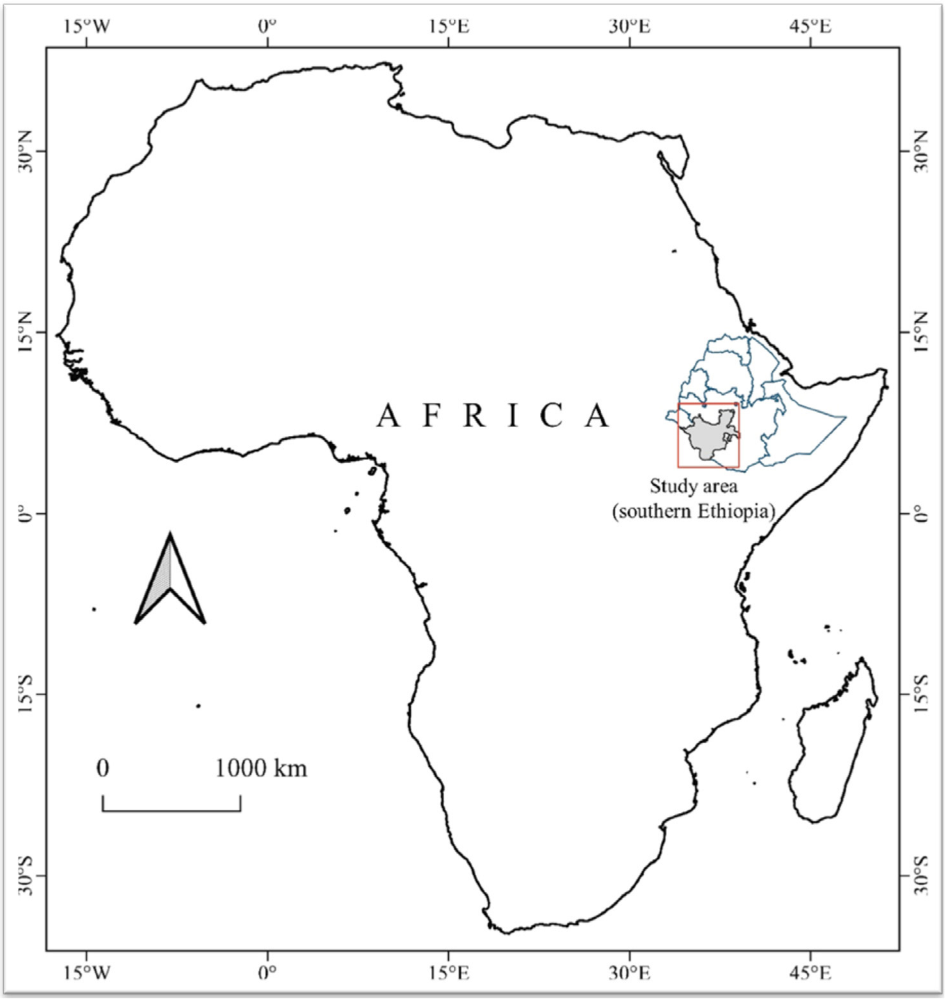

Figure 2. *Study area map (author 2021).*

system established for mutual aid mainly to support families by covering funeral costs and helping in kind through labor contributions in farm activities for those who suffer from labor shortage. The area is also characterized by subsistent farming, poor access to essential resources, low-income, high poverty, and vulnerability to climate extremes (Dowsing and Cardey, 2020). Development partners have implemented several CSA activities in the study area—such as the CGIAR research program on Climate Change, Agriculture, and Food Security (CCAFS) and InterAide.

2.2. Sampling methods and data collection techniques

The study employed a multistage sampling technique where a combination of sampling procedures was followed. In the first stage, Doyogena District from the Southern Nations, Nationalities, and Peoples' Region (SNNPR) was selected purposively because it is one of the ten regional states found in Ethiopia where CSA practices have been tested and promoted for a decade. In the second stage, two adjacent Kebeles (the lowest level administrative units of the Federal Democratic Republic of Ethiopia), one from the adopters and the other from the non-adopters, were selected using random sampling techniques to reduce incidences of the spillover effect and avoid selection bias. These two Kebeles are adjacent to each other and are assumed to have similar topography, harvesting and planting seasons, and cropping and livestock systems. In the third stage, with the help of extension personnel and peasant associations leaders, four villages from each Kebeles in total eight villages were identified for the final households' interview.

In order to select households for the interview, we used the randbetween function in Microsoft Excel (Mesfin et al., 2020). A total of 385 households, 80.5% male and 19.5% female respondents, were selected from 10267 sampled population using Cochran's formula (Heinisch and Cochran, 1965) proportionally and figured as follows (Eq.1)

$$n=\frac{Z^2pq}{e^2}=\frac{(1.96^2)(0.5)\left(0.5\right)}{(0.05)^2}=385\ \textit{households} \tag{1}$$

Where: n indicates the sample size for the study p = estimated variance in the population, q = 1-p, Z = Z-score at the desired confidence level and e is the acceptance error (5%) at 95% level of confidence, and Z = 1.96.

Both quantitative and qualitative data were collected using focused group discussions (FGDs), key informant interviews (KIIs), semi-structured questionnaire, meteorological records of the last 34 years, and direct observation (Creswell and Creswell, 2017). FGDs and KIIs from each village were conducted to capture comprehensive information on farmers' knowledge and perception of rainfall and temperature patterns for the last three decades, climate risks, perceived impacts of weather variations, and CSA adaptation measures toward climate change. The questionnaire and checklist were pretested to validate the questionnaire before the actual data collection phase. Secondary data were also collected from different sources, such as published articles and policy-related working documents.

2.3. Data analysis and empirical model

The collected data was entered, coded cleaned, and analyzed using STATA software version 14.2. Descriptive statistics were employed to analyze institutional characteristics, socioeconomic issues, and farmers' awareness about climate variability and change and its associated impacts. We employed Heckman sample selection model to empirically analyze the drivers of farmers' perceptions and CSA adoptions. The dependent variables used for the selection model is farmers' perception of climate change, including changes in rainfall and temperature and adaptation measures. The dependent variable for the outcome model is farmers' adaptation to climate change through adoption of climate smart agricultural practices. The independent variables used in both models included different socioeconomic, demographic characteristics, and environmental and institutional factors based on the recent literature on farmers' knowledge and perception of climate change and adaptation to climate change and variability. Qualitative data collected from FGDs, KII, and direct observations were analyzed using narrative analysis methods.

Previous studies on farmers' perceptions of climate change and variability used different regression models including nominal or ordinal probit regression model (Byg and Salick, 2009), binomial probit model (Maddison, 2006; Piya et al., 2012), multivariate discrete choice model (Nhemachena and Hassan, 2007), Heckman probit selection model (Deressa et al., 2011), binary probit model (Khan et al., 2021), binary logit model (Onyeneke et al., 2018), and ordinary least square (OLS) estimation (Huong et al., 2017; Marie et al., 2020; Nyang'au et al., 2021; Sertse et al., 2021; Uddin et al., 2017). However, this cross-sectional survey-based empirical research work focused on the measured factors with a biased causal effect on the given outcome variables (Wooldridge, 2016; Wuepper et al., 2018). The present study employed the Heckprobit model to correct selectivity bias (Mehiriz and Gosseln, 2021; Sojons, 202). Adaptation to climate change and variability follows two-step process that involves perceiving that climate is changing and then in the second step, preparation to take adaptation measures through CSA adoptions (Morton 2007; Deressa et al., 2011). In this regard, two step maximum likelihood procedure can be used to correct this selection bias (Heckman, 1976). Heckman's selection model considers in the first stage farmers' knowledge and perception to climate change (selection model) and in the second stage (outcome model). This model considers farmers' climate change adaptation measures, which are conditional on the first stage. In other words, farmers will only adapt to climate change if they understand it or have some knowledge about it. Heckman's probit selection model assumes that there is an underlying relationship exists which consists of the latent equation given by the following (Eq.2):

$$yj = \beta xj + \mu 1j \tag{2}$$

where yj is the latent variable; that is to say, the propensity to adopt climate change measures, **x** is a key vector of explanatory variables which affects adaptation measures, β is the parameter estimate, and $\mu\ 1_j$ is the error term. In this case, only the binary outcome given by the probit model is observed as follows (Eq.3):

$$yj^{probit} = (yj > 0) \tag{3}$$

The dependent variable can be observed only if the observation of j is observed in the selection equation (Eq.4):

$$yj^{select} = (\mathrm{zj}\delta + \mathrm{u2j} > 0) \tag{4}$$

$$\mu 1 \sim N(0, 1)$$

$$\mu 2 \sim N(0, 1)$$

Corr($\mu 1$, $\mu 2$) = ρ

Where yj^{select} is whether the farmers are perceived climate change or not, z is the vector of explanatory variables which affect farmers' perception of climate change δ is the parameter estimate and u1 and u2 are the error terms which are normally distributed with mean zero and variance one. In this case, the first stage of Heckman's two-stage model is the selection model(eqn4) which indicates the farmers' perception of climate change, and the second stage of the outcome model (Eqn. 2), which represented farmers' adoption of measures to combat climate change, and it is conditional to whether farmers are perceived to climate change. When the error terms are correlated from the selection and outcome model or when ρ≠0, the standard probit model applied to Eq. (2) gives biased estimates. Thus, the Heckman probit model helps to get consistent and efficient estimates for all parameters included in the model (Van de Ven and Van Praag, 1981). Hence, this study employed the Heckman probit selection model to analyze farmers' knowledge of climate change and adaptation measures in southern Ethiopia. The dependent variable for the selection equation is farmers' knowledge and perception of climate change and the dependent variable for the outcome variable is whether farmers are adopted CSA practices or not to climate change and its impacts. The explanatory variables hypothesized to affect farmers' detection of climate change and adaptation measures are chosen based on the climate change-related literature and data availability (Table 1).

The variables used in the model were selected based on the existing literature and depicted in Table 1. Previous studies have either measured climate perception related variables using Likert scale (Nuamah and Botchway, 2019; Behailu et al., 2021; Jellason et al., 2021; Sertse et al., 2021) or treated perception as a dummy variable (Makate et al., 2019; Marie et al., 2020; Nyang'au et al., 2021; Roco et al., 2014). In this study, perception was measured following multistage procedures. In the first stage, open-ended questions were prepared, and the farmers were asked

Table 1. Variables summaries used in the model.

Variable	Explanation	Mean	Std. Dev.
CSA Adoptions	1 for adopters; 0 otherwise	0.618	0.486
Climate change perceptions	1 for perceived; 0 otherwise	0.868	0.339
Age	The actual age of the household head in years	50.423	13.461
Education	Level of education in years	3.112	3.854
Family size	The number of family members in the household	7.429	2.451
Gender	1 for male, 0 otherwise	0.805	0.397
Landholding size	Total crop landholding in hectares	0.617	0.466
Farming experiences	The actual farming experience of the household	25.67	13.538
Distance market	The distance of input and output market in km	4.871	5.7
Access climate info	1 for access to climate information; 0 otherwise	0.771	0.42
Contact extension	The number of annual contact with extension agents	5.117	12.298
Training received	1 if the farmers had received training; 0 otherwise	0.732	0.443
Access credit	1 if the farmers had access to credit; 0 otherwise	0.286	0.452
Social membership	1 if the farmer was a member of a social group; 0	0.956	0.206
TLU	The tropical livestock unit	2.442	1.868
Income	Estimated annual income in Ethiopian currency	12571.66	907.48
Soil fertility	1 if a farmer has fertile soil; 0 otherwise	0.63	0.04
Rainfall	Average annual rainfall in millimeter (mm)	1249.1	441.336
Slop of farm plot	1 if farm plot is steep slop; 0 otherwise 0.56 0.032		

in chronological order (e.g., "Do you know what is climate change? Have you perceived any change in climatic conditions in the recent past? Which climate factor/s did you perceive as a change? What changes have you observed concerning the factors you have perceived in the last three decades?") Depending on the questions asked the farmers and the answers provided, the farmer would be considered to "perceive" changes in their climate based on the response given series of aforementioned questions. In the second stage, a farmer's perception was treated as a dummy variable that takes the value of 1 if the farmer perceived that the climate is changing, and 0 otherwise.

Few studies have conducted theoretical and empirical exploration of evaluating smallholder farmers' CSA adoption decisions under different circumstances. For example, Wuepper et al. (2020) and Aryal et al. (2020) studied non-cognitive skills using agriculture technology adoption as dependent variables. A series of questions were asked to the farmers to define the variable CSA adoptions: "Have you adopted one or more of the available CSA options in your farm plot to overcome the climate change impacts? What CSA practices and technologies do you use among the listed alternatives?" Farmers who adopted one or more CSA options are considered adopters; whereas those who did not adopt any of the CSA practices are taken to be non-adopters.

Access to extension, market, credit services, income, social network, and farmers' training are institutional characteristics expected to improve the adoption measures and reduce the negative impacts of changing climate (Azumah et al., 2021). However, limited access to extension and lack of credit services were the main barriers to CCA (Teshome et al., 2021). Access to climate information is expected to help farmers guide and take adaptation decisions (Nidumolu et al., 2021). Farmers' information exploration behavior is determined by the aspiration of the information exploration and farmers' capability to grasp social capital and network skills. The climate information content they need, and the potential sources of information enable them to furnish the information exploration behavior; this would increase farmers' knowledge and perception of climate change.

Furthermore, social network services could serve as an important source of information for farmers (Chuang and Schechter, 2015). Livestock ownership is expected to reduce vulnerability to climate change risks and improve income and food security (Aryal et al., 2020; Mujeyi et al., 2021).

3. Results and discussion

3.1. Socio-demographic background

Table 2 presents descriptive statistics. About 80.5% are male-headed households. Most of the agricultural activities in the field require physical labor, and men are more likely than women to participate in such work (Tsige et al., 2020). In a study on eastern Ethiopia, Teshome et al. (2021) reported that 94% of the observations were from male-headed households. Meanwhile, Kristjanson et al. (2017) indicated that in Saharan Africa, women tend to have less access to resources, remain disadvantaged, and less frequently adopt particular CCA strategies than their male counterparts. Bryan et al. (2018) recommended an investigation on the entry points of considering gender sensitive CCA measures across local contexts for effective implementation of adaptation strategies.

Table 2. Farmers' awareness and perceptions of climate change and shocks.

Farmers response to climate change and variability	Lemisuticho (%) (No. = 238)	Begedamo (%) (No. = 147)	χ^2 test
perception of climate change			5.011
Yes	**86.61**	**76.99**	
No	13.39	23.01	
Temperature trend in the last 30 years			11.79
Increase	**71.97**	**71.92**	
Decrease	13.81	11.64	
No change	6.28	9.59	
Don't know	7.95	6.85	
Rainfall trend in the last 30 years			0.878
Increase	35.15	37.89	
Decrease	**50.63**	**55.67**	
No change	7.53	8.90	
Don't know	6.69	7.53	
Hot days in the last 30 years			6.617
Increased	73.22	71.23	
Decreased	13.81	8.22	
Stayed the same	6.28	12.33	
Don't know	6.69	8.22	
Rainfall days in the last 30 years			
Increased	35.63	42.47	2.80
Decreased	50.98	39.73	
Stayed the same	7.98	10.27	
Don't know	5.44	7.53	
Level of recent rainy season precipitation			6.836
Very high	7.95	5.48	
High	37.24	32.19	
Normal	21.76	28.08	
Low	26.36	21.92	
Very low	6.69	12.33	
Encountered drought in the last 30 years			2.875
Yes	58.16	63.70	
No	34.73	32.88	
Don't know	7.11	3.42	
Flooding event in the last 30 years			5.253
Yes	59.00	68.49	
No	38.08	30.82	
Don't know	2.93	0.68	
Pest and disease occurrence in the last 30 years			3.626
Yes	90.79	86.99	
No	5.86	10.96	
Don't know	3.35	2.05	

Source: Authors' computation based on survey data 2021

The average family size of the households' ranges between five and seven members, and a large family size in the study area is considered an asset. The majority of family members spent their time in the field due to the labor-intensive nature of agricultural activities and the existence of a large number of family members in a household (Mvula and Dixon, 2021). The average farming experience of the smallholder farmers in the area is about 25 years. The result supports the previous studies, as the higher the farming experience, the better opportunity to employ effective adaptation strategies that improve farmers' resilience to the changing climate (Mwungu et al., 2018; Nyang'au et al., 2021). Concerning the education level of the households, 37.5% of the household heads have attended primary school, and only 1% of the households attended tertiary school level. During focus group discussion (FGD) and key informant interview (KII), farmers reported that their education experience has helped them to adopt improved farming technologies that increase agricultural productivity and enhance their resilience against a changing climate (Nyasimi et al., 2017). Approximately 85% of the household heads were married.

3.2. Farmer's perception of climate variability and its impacts

The study measures farmers' perception of climate change and variability using three key variables, including general understanding of climate change, rainfall, and temperature changes. Farmers were asked the general question about their feelings regarding changing climate and variability. The responses were used to measure the farmers' perceptions. The follow-up questions were asked respondents to furnish evidence on the climate change and variabilities they observed/experienced in the last three-decade sand most participants were aware of climate change. The results indicated that most farmers who participated in FGD identified climate change as something which is already happening and described its negative impacts on their farming activities. The result agrees with the findings of a study conducted in the Central Rift Valley in Ethiopia that found that 90.3% of respondents have considerable awareness on the meaning of climate change (Hundera et al., 2019). Farmers' responses to climate change and its impact were sometimes inconsistent, and they were asked again to validate their response about the word climate change. The KII from Lemisuticho Kebele who lived in the area for close to 35 years reported as indicated that 20 years ago, the amount of rainfall used to have a relatively normal pattern and it was sufficient for planting. However, in the recent decade, the duration and number of rainy seasons like what an Amharic speaker would call "*belg*" (small rainy season) and "*meher*" (harvesting season) season had declined and followed erratic nature of patterns. Regarding temperature change, a key informant reported that temperature has increased compared with the last two decades. Moreover, owing to temperature increment, several water springs have dried out, and even the amount of water in local rivers became too small when compared with that in the last two decades.

Many respondents (81.8%) perceived that reported that to the best of their understanding, climate condition has changed since the last three decades. Similarly, 71.95% farmers reported that the temperature has increased, and 53.15% of them reported that the amount of rainfall has decreased (Table 2). A farmer in KII participation explained that within the last 5–10 years, the rainfall pattern became unpredictable and had short duration with either early or late onset rainy seasons. Meanwhile, frequency of dry spells and extended droughts has increased. The result of farmers' perception was consistent with the metrological observations of rainfall and temperature trends in the study area (Belay et al., 2021).

The result indicated that (81.8%) of the respondents have perceived increasing temperature and decreasing rainfall distribution in the last three decades, particularly in the recent 5–10 years. Farmers reported that drought, extreme flooding, pest, and disease are the main climate change-related problems in the area. The finding agrees with the three studies (Concha, 2018; Hundera et al., 2019; Teshome et al., 2021) indicating that most farmers realized that the climate is changing.

Survey participants reported the main changes in rainfall and temperature observed in their localities; 71% of respondents claimed that the rainfall and temperature trends become increasingly unpredictable. Following the unpredictability and erratic nature of rainfall and temperature, farmers' agricultural activities have been negatively affected by such changes. In response to the climate change impacts, farmers have employed different CSA measures as adaptation strategies, including soil and water conservation (SWC), agroforestry, improved crop varieties, cut and carry system, and residue incorporation.

Supporting the decline of rainfall and increment of temperature reported by the survey participants, the focus group discussants and key informants confirmed that unpredictable and intensive rainfall distribution was experienced and largely affected farming activities. This result is supported by Weldegebriel and Prowse (2017), who conducted their study in northern Ethiopia and indicated increasing trends of temperature and rainfall variables affected smallholder farmers. The FGD participants added that overall changes in temperature and rainfall distribution have become pressing in the last 5–10 years and negatively affected the livelihoods of the local communities.

The farmers in FGDs boldly explained that about 30 years ago, the rainy seasons and planting, cultivation, and harvesting times were predictable. However, in recent decades, particularly in the last decade, they have been experiencing unpredictable changes, including a short duration of rainfall, massive flooding, crop failures in the field, livestock pests and diseases, and human health problems. This result is consistent with the recent study conducted by Teklewold et al. (2019) in Ethiopia, indicating that unpredictable rainfall and temperature affect smallholder farming systems. Meanwhile, Hundera et al. (2019) conducted a study in the Central Rift Valley of Ethiopia on smallholder farmers' perception; they specified that climate has changed and affected farmers' agricultural activities. Minda et al. (2018) studied factors affecting adaptation measures in Ethiopia; they highlighted that crop failure, massive soil erosion, and water shortage are the main climate change-related problems. The focus group discussants mentioned frequent drought episodes, with some having no historical comparisons occurring in the study area for the last three decades and affecting many people. These drought events reported by the farmers are conceded with the metrological findings of Belay et al. (2021) related to *El Niño* Southern Oscillation (ENSO) events, including *El Niño* events in 1987, 1991, 2001, 2009, 2015, and 2019. The drought periods coincided with an extended drought condition from April to November, which is the region's main cropping/planting season. Farmers explained similar findings reported in recent studies conducted in East and West Africa (Apollo and Mbah, 2021; Dapilah and Nielsen, 2020).

3.3. Farmers perceived impacts of climate change and variability

Smallholder farmers perceived that climate change, and the erratic nature of rainfall distribution were the major threat to their livelihood systems. Farmers were asked to indicate to what extent climate change and variability affected their livelihood systems. The results are presented in Table 3. Farmers reported that climate change and variability highly affected major livelihood assets, including economic, natural, physical, human, and social systems.

Farmers reported that climate change caused the decline in crop yield (85.85%), loss of household income (89.57%), reduced productivity of agricultural land (82.5%), food shortage and insecurity (79.47%),

Table 3. Smallholder farmers' perceptions of the impact of climate change-related events.

Perceived climate-related impact	Lemisuticho (No. = 238) Respondents	Begedamo (No. = 147) Respondents	Mean (%)
The decline in crop yield	203(85.31)	127(86.39)	85.85
Loss of income	211(88.65)	133(90.47)	89.57
Decline in household consumption	204(85.71)	124(84.35)	85.03
Food shortage, food insecurity	184(77.31)	120(81.63)	79.47
Death of livestock and human mortality	90(37.82)	41(27.89)	32.855
Reduced productivity of agricultural land	166(69.75)	140(95.24)	82.5
Reduced water availability and quality	136(57.14)	80(54.42)	55.78
Increase cost of farm inputs	177(74.37)	109(74.15)	74.26
Increase cost of health care	102(42.86)	46(31.29)	37.075
Reduction in soil fertility	157 (65.97)	114(77.55)	71.76
Loss of Forest resources	167(70.16)	125(85.03)	77.595
Unemployment	106(44.53)	97(55.74)	50.14
Increase food prices	**211(88.65)**	**143(97.23)**	**92.94**

Source: Authors' computation based on survey data 2020/2021.

increased food price (92.94%), and increased cost farm input (74.26%). Consistent with this result, the findings of Araro et al. (2019) indicated that in Southern Ethiopia, 52.2% of the households reported decreased land productivity and lower crop yield production. In the same study region, Megersa et al. (2014) indicated that climate change negatively affects livestock production and crop yields, and increases crop-livestock pest and diseases. Moreover, Mavhura et al. (2021) reported that climate change and variability affected major livelihood systems in Zimbabwe, the farming system in Ethiopia (Teshome et al., 2021), crop production, and food security in Kenya (Kogo et al., 2021; Mairura et al., 2021). Climate-related impacts become pressing on farmers' overall livelihood systems, leading to farmers' aspiration failure (Dalton et al., 2016; Islam et al., 2021). The aspiration failure of farmers has consequences, such as cognitive depiction, poverty, food insecurity, and an inadequate response to climate shock (Mekonnen et al., 2021). Farmers who strive to overcome climate-related shocks and achieve their aspirations to for future life opportunities need sound policy support in the agriculture sector (Genicot and Ray, 2017; Suckall et al., 2017).

However, farmers have also reported they were using different sources of information regarding climate variability and change (Figure 3). Their prior experience and beliefs on climate change perception could affect their interpretation of new climate information, leading to information bias and reaching a preferred conclusion (Sambrook et al., 2021). In the FGD, participating households were asked, "What were the main channels of accessing climate information?" A total of 40.97% and 43.33% of participants responded that radio and development agents were mostly used as the main sources of climate information in both Lemisutich and Begedamo kebele, respectively. Some farmers became aware of climate change and its impact through a social group membership network. The result is consistent with the findings of (Henriksson et al., 2021).

Henriksson et al. (2021) explored understanding gender differences of availability and accessibility of climate information in the context of Malawi. According to them, radio is dominantly used as a means of accessing climate information. Meanwhile, the social group is a means of communication tool and contributes a vital role in implementing collective management of the farming system among rural communities (McNaught et al., 2014). It creates the chance of exchanging knowledge with other farmers to understand climate change and new farming activities (Dapilah and Nielsen, 2020).

3.4. Farmers' adoption of CSA practices

Despite the increasing risk of climate change which includes drought, flooding, soil erosion, pest and diseases and its impacts on crop livestock production, farmers who have been affected by climate change made their response measures by adopting multiple CSA practices (Amare and Simane, 2017; Sertse et al., 2021). The most common CSA practice strategies adopted by farmers in the study include SWC with biological measures, crop rotation (cereal/potato), improved crop varieties (high yielding beans, potato wheat), agroforestry systems (wood perennials crops), improved breeds (small ruminants), and residue incorporation (wheat/barely). Adaptation strategies are imperative in addressing climate change and variability (Keshavarz and Moqadas, 2021). This study revealed more than 10 CSA practices that are implemented by the farmers (Figure 4). Farmers' perceived impacts of climate change could increase the promotion and adoption of available CSA practices and technologies as an adaptation strategy (Zerssa et al., 2021). The adoption of CSA practices increases agriculture productivity, enhances farmers' resilience to climate shocks, and reduces greenhouse gas (GHG) emissions (Lipper et al., 2017). In response to climate change impacts, farmers in FGDs and KIIs were asked specific adaptation measures in their farm plot. Results reveal that SWC with biological measures was the highest: 83.58% mostly adopted these strategies (Figure 4). Soil erosion is a predominant problem that affects soil fertility and agricultural production due to the steep sloped nature of the study area's landscape. Controlling the severe soil erosion problems requires establishing an anti-erosive structure that integrates the association of grass and legumes for forage production and maintaining soil moisture. These biological practices allow solving multiple problems at a time, including reducing soil erosion, improving soil fertility, reducing water retention, resolving fodder scarcity, and reducing open grazing (Ayele et al., 2012). In the context of Rwanda, Rutebuka et al.(2021)reported that SWC with biological measures and terracing techniques were productive in controlling soil erosion.

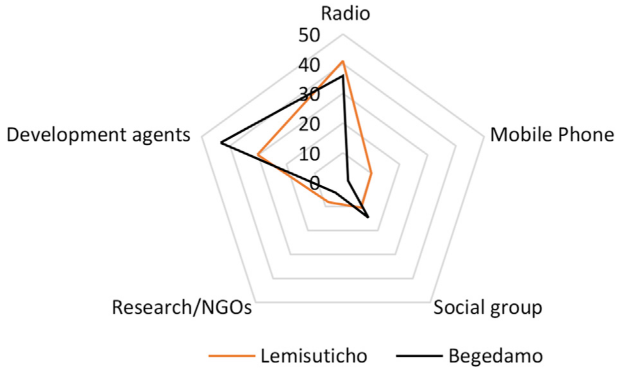

Figure 3. Main channels of climate information for farmers.

Following SWC practice, the cut and carry system, green manure, and crop residue incorporation are the most widely practiced CSA adopted by the farmers. Smallholder farmers mainly relied on natural grasses and crop residues to feed their livestock. Growing fodder grass as the crop in their farm plot was uncommon, and it is a recent intervention. With the increasing pressure on collective pasture lands and the decrease in fodder availability, farmers have adopted livestock management based on a "cut and carry" feeding system, with new practices to meet the needs of breeding systems. Throughout the different periods of the year and according to farmers' production capacity, cattle feed comprises different sources. Farmers from the FGD and KII reported that searching for feed for their livestock is a daily labor-intensive task usually carried out by women or children. Depending on the time of the year and the size of the herd, collecting forage can require about 2–4 working hours a day. Furthermore, Balehegn et al. (2020) explored improving livestock feed in low and middle-income countries. They reported that feed and feeding-related issues are ranked as the primary challenges because livestock production is fodder demanding and fodder production is affected by drought.

The total effect of different CSA practices on crop yield production in both adopters and non-adopters was estimated and presented in Table 4. It shows the substantial crop production difference between CSA adopters and non-adopters. Compared with the non-adopters, adopters have reported relatively higher yield production of cereal and perennial crops and vegetables. The adopters of CSA coproduction have a higher average yield than non-adopters. For example, the wheat and potato production of adopters has a higher yield of 36.84% and 40%, respectively, compared with the non-adopter in the production season (Table 4). Notably, with less fertilizer input use and other costs, the CSA adopters have a significantly higher yield than the non-adopters do. Following the application of SWC with biological measures, green manure, and residue incorporation, the soil fertility status of the CSA adopters is better than that of the non-adopters.

The finding of this research agrees with those of previous studies (Anteneh and Asrat, 2020; Belay et al., 2021; Borrell et al., 2020; Waaswa et al., 2021). For example, Waaswa et al. (2021) studied CSA and potato production in Kenya; they reported that the adoption of CSA practices yields higher potato production (on average, 15 tons per hectare) than conventional farming. Belay et al. (2021) also reported that potato production with CSA adoption yields more than 17 tons per hectare. Moreover, Anteneh & Asrat (2020) reported that with improved

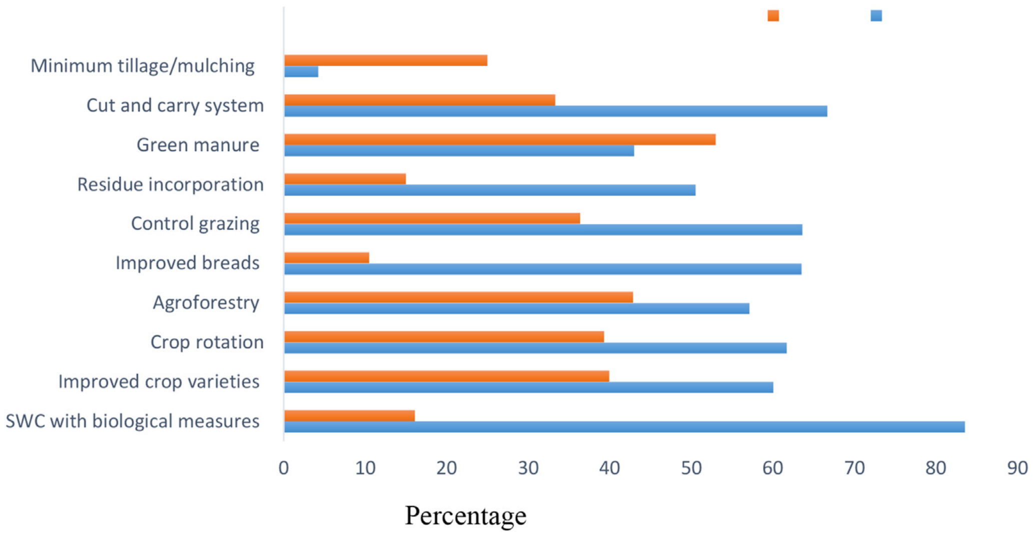

Figure 4. Farmers' adaptation measures using different climate-smart agriculture practices in the study area SWC techniques (i.e., terracing, soil bunds, and *desho* grass strips) are widely used as conservation practices by farmers in the study area. This practice improves soil moisture and reduces runoff in erosion-prone villages of the district. Soil and water conservation (SWC) with biological measures is one of the key adaptation practices to ensure increasing agriculture productivity against continuing climate extremes and building the resilient capacity of farmers (Njeru et al., 2016).

agricultural practices, farmers produce an average of 2.9 ton per hectare of wheat yield in the production season. Hence, the results indicated that CSA adoption increases crop production and income with efficient use of the available resources.

Farmers also asserted the primary constraints facing the implementation of CSA practices, as CCA measures, including limited farm inputs and weak institutional support, remained the primary problems in their localities (Figure 5).

The main constraints identified by farmers include limited credit services, lack of useful information, and shortage of labor, which hinder the adaptation strategies (Figure 5). The result agrees with the findings of Marie et al. (2020), who studied the adoption of CCA strategies in Northwestern Ethiopia. They stated that access to climate information, annual income, and market access are the main factors determining farmers' perceptions of climate change.

3.5. Factors determining farmers' perception of climate change and adoption of CSA practices

The Heckman probit selection model was run, and the model has been tested for its appropriateness over the standard probit model (i.e., a probit model does not account for selection). The result shows that the sample selection problem was found and depending on the error term in both the outcome and selection model justifying that the use of Hackman selection probit model with rho is significantly different from zero (Wald $X^2 = 10.25$, with $p < 0.001$). In addition, the likelihood function of the Heckman probit model was significant (Wald $X^2 = 82.45$, with $p < 0.001$) and this indicates that it has strong explanatory power. The result indicated that most explanatory variables in both outcome and selection model and their marginal values are found to be statistically significant at $P < 0.05$. Marginal effects measure the expected change in the probability of farmers' perception and adaptation measures concerning the unit change in an explanatory variable. The selection model determines the likelihood of perception of climate change and the likelihood of farmers' adaptation measures to climate change. The dependent variable in the selection equation is dichotomous indicating whether farmers perceive climate change or not, and the dependent variable in the outcome variable is also dichotomous; indicating whether farmers adopt improved adaptation measures. The result from the selection model analyses factors affecting climate perceptions and the result from the outcome model analyses the factors which affect farmers' CSA adoptions (Table 5).

The results from the outcome model that analyzes factors affecting farmers' CSA adoption indicated that most of the explanatory variables positively and significantly affected the probability of CSA adoptions, which includes education, family size, gender, landholding size, farming experience, access to climate information, training received, social membership, livestock ownership, farm income, and extension services.

For example, a one-year increase in education likely increases the adoption of CSA practices by 21.40%. Farmers with formal education experience increased knowledge and skills of cognitive aspect adaptation measures and capacity (Walker et al., 2021). A recent study by Aryal et al. (2020) on climate risk and adaptation measures in East Africa and Southern Asia indicated that in most countries, including Ethiopia, Nepal, and Bangladesh, the households with better education levels need local institutional support for their intervention as they have knowledge and understanding of climate change and corresponding adaptation practices. The literacy level contributes to mainstreaming innovative farming practices and is expected to enhance the adaptive capacity of farmers by obtaining and using useful climate information applicable to CSA practices (Abegunde et al., 2020).

Table 4. Summary of crop yield production estimate (2021 production season).

Crop type	Adopters ton/ha	Non-adopters ton/ha	Mean difference	%
Wheat	3.8	2.40	1.4	36.84
Barley	2.75	2.00	0.75	27.27
Legumes	1.6	1.10	0.5	31.25
Potato	20.00	12.00	8.00	40.00
Enset	83.2	67.35	15.85	19.05
Vegetables	4.70	3.25	1.45	30.85

Source: Authors' computation based on survey data 2020/2021.

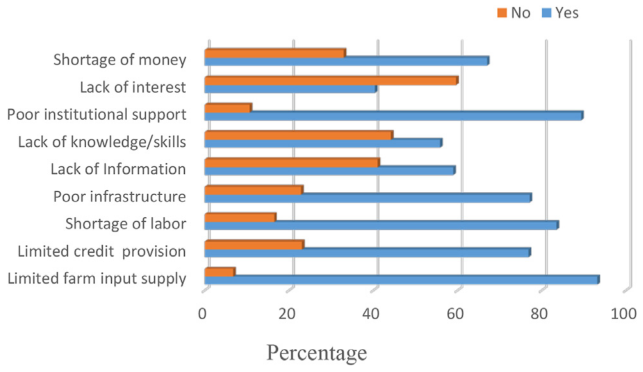

Figure 5. Constraints impeding adaptation to climate change.

Table 5. Results of the Heckman probit selection model.

Variables	Outcome model				Selection model			
	Regression		Marginal value		Regression		Marginal value	
	Coefficient	z-Value	Coefficient	z-Value	Coefficient	z-Value	Coefficient	z-Value
Age	0.012	1.93	0.012	1.93	0.026	2.87	0.003	2.45
Education	0.044	4.98	0.214	2.35	0.154	16.61	0.026	5.53
Familysize	0.031	1.83	0.031	4.39				
Gender	0.103	0.89	0.103	0.89	0.016	0.08	0.003	0.48
landholding_size	0.160	8.46	0.161	2.17				
farming_epereinces	0.024	4.19	0.039	6.90	0.028	4.19	0.036	2.85
access_extension	0.137	3.43	0.137	4.58				
distance_outputmarket	-0.012	-1.71	-0.012	-1.71				
access_climateinformation	0.402	5.99	0.202	6.79	1.084	5.99	0.231	8.56
contact_extension	0.213	6.20	0.013	2.93				
Training_received	0.224	2.21	0.224	2.21				
access_credit	0.001	0.01	0.001	0.01				
Social_member	0.206	20.29	0.106	2.59	0.620	1.70	0.005	2.72
TLU	0.013	5.78	0.013	5.77				
Annual income	0.235	2.68	0.235	2.68				
Soilfertility	0.135	4.71	0.135	1.37				
slop_farmplot	-0.012	-0.14	-0.012	-0.14				
rainfall_var					0.069	1.97	0.020	2.21
Constant	0.490	2.65			0.121	2.79		
Total observation 385								
Censored 79								
Uncensored 306								
Wald Chi- square (zero slopes) 82.45, $p < 0.001$								
Wald chi-square (independent equation)	**10.25, $p < 0.001$**							

Source: Authors' computation based on survey data, 2020/2021.

The level of education increases farmers' agriculture production because educated farmers are relatively more risk-takers and readily embrace innovative ways that apply new agricultural practices. Moreover, education increases farmers' ability to get, interpret and easily understand climate-related information, thus coming up with possible solutions to climate change-related impacts and corresponding adaptation measures. Deressa et al. (2011) and Arunrat et al. (2017) reported that more educated households are more likely to adapt to climate change than less educated ones due to new experience in knowledge and agricultural technologies. The effect of a high education level increased the probability of farmer adaptation due to their greater exposure to new knowledge and technologies. Similarly, Croppenstedt et al. (2003) and Deressa et al. (2011) reported that highly educated farmers are more likely to adapt better to climate change than less educated households. However, this result contrasts that of Wekesa et al. (2018), who stated that the years of education have negatively influenced selected CSA practices.

The likelihood of farmers adopting CSA practices improves by 3.10% for every additional productive family in the household. This due to the fact that CSA is labor-intensive; thus, large family sizes produce a considerable labor force for effective application for the new agriculture practices in the farm plot (Ojoko et al., 2017). If the cultivated landholding size increases by 1 ha, farmers' adoption of CSA practices increases by 16.10%. Agricultural land is the key resource for agriculture production: the more the availability of productive land, the more CSA adoptions. This implies that after extreme rainfall events, land fragmentation was ranked as the second main constraint. Therefore, additional land resources could be used for different agricultural practices and reduce uncertainty risks. If farming experience increases by a year spent on the farm, the likelihood of farmers CSA adoption s increases by 3.90%. This agrees with the findings of Onyeneke et al. (2018), Ringler et al. (2010), and Silvestri et al. (2012), who confirmed the greater tendency for experienced farmers to perceive climate, adjust the farming system in response to climate variability, and promote the uptake of CSA adoptions.

The availability and accessibility of climate information influence farmers' knowledge and perception of climate change (Ado et al., 2019). Access to education helps farmers to overcome the barriers of climate change-related information and enhances smallholder farmers' adaptive capacity by establishing a strong connection between farmers and agriculture extension providers (Kumar et al., 2021). Access to climate information increases the chance of adopting selected practices by 20.20%. In particular, access to information on weather conditions, extension services, and input prices could reduce the barriers in implementing CSA, practices. According to Issahaku and Abdulai (2020) and Onyeneke et al. (2018), the adoption of CSA practices is largely dependent on climate information, and adopters would have better exposure to the innovative farming techniques and become more aware of potential climate risks and uncertainty. Households who belong to social membership have access to agricultural-related information and are anticipated to influence the CSA adoption level positively. Moreover, social group members increase the likelihood of CSA adoption by 10.6% compared with the farmers who had not joined the social groups (Zougmoré et al., 2021). Joining the social groups is considered an asset to building the community's social capital, that plays crucial roles in sharing farming experiences, and having a strong social network helps increase CSA adoption(Abegunde et al., 2020). The results from the selection model that analyzes the factors influencing farmers' perception to climate change indicate that the age of the household head, level of education of the household head, farming experience, and access to climate information affect perceptions of farmers positively. Similar findings were reported by Deressa et al. (20211) and Asrat and Simane (2017) who studied on adaptation benefits of climate-smart agricultural practices and Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. The factors investigated as affecting farmers' perception to climate change and their adaptation measures are directly related to the development activities of the Ethiopian government policy intervention to reduce poverty and enhance adaptive capacity of the smallholder farmers. However, more development activities need to be done in terms of establishing effective adaptation measures to support the rain fed agriculture systems and create awareness to climate change and variabilities and promote improve agriculture practices and technologies.

3.6. Government policies, support, and strategies toward the agriculture sector in Ethiopia

CSA intervention requires sound policy directions and institution support (Ampaire et al., 2020). Policy support is essential for disseminating adaptation and mitigation practices (Filho et al., 2018). In Ethiopia, many policy documents have been developed for the agriculture sector to improve agriculture production and reduce poverty and food insecurity (Hameso, 2018). Some policy documents that were developed and used for decades include agriculture development-led industrialization (ADLI). The document was developed in 1995 to enhance agricultural production, national food sufficiency, and income for rural communities (Zewdie, 2015). After a few years of implementation, ADLI was supplemented by other programs, including the Sustainable Development and Poverty reduction program, and it was implemented from 2000 to 2005. Moreover, Plan for Accelerated and Sustainable Development to end poverty was adopted again from 2005 to 2010. Meanwhile, Climate Resilient Green Economy (CRGE) Growth and Transformation Plan I&II was implemented from 2015 to 2020 (Dube et al., 2019). One can learn that the policy documents in Ethiopia have been struggling to improve the agricultural production and food self-sufficiency to rural communities against changing climate (Welteji, 2018). Due to the severe impact of climate change posing in the agriculture sector, the government of Ethiopia has been promoting a new policy document, that is, CRGE in 2011. The main objective of the policy document is to achieve three main approaches: low carbon development, greenhouse gases emission (GHGs) reduction, and capacity building reaching the middle-income country-level in 2025.

Ethiopia had no separate policy document to promote CSA practices, and the current policy document has combined new agriculture practices and technologies for improving crop-livestock production system, GHG reduction, and achieving food security in Ethiopia (Njeru et al., 2016; Zerssa et al., 2021).

The country has also developed a national forest policy proclamation and implemented it since 2018. The forest proclamation enables farmers and associations to obtain ownership rights and promote agroforestry and CSA practices (McLain et al., 2019). To adopt the improved agriculture technologies, experts and KII have proposed potential suggestions. Awareness among the local communities on improving the farming system and sustainable livelihood diversification must be promoted, and available land-use rights need to be informed (McLain et al., 2019). In this regard, participatory natural resource management is the key task for implementing the endorsed policy documents, and local communities shall be involved in every decision-making process (Tsegaye et al., 2017). Non-government organizations and government development agents working with the farmers pointed out that during the actual intervention of the CSA adoption process, agricultural policy strategies must be in place, and local institutions should give due attention to small-scale agriculture farming (Wossen et al., 2018). Furthermore, integrating research findings with a human dimension, behavior, and environmental change should be considered to identify and develop sound policy options to support climate resilient agriculture intervention and produce food under changing climate(von Braun, 2020). Developing sound policy documents is essential to improve farmers' understanding and intentions to implementing CCA measures at their farm plots.

4. Conclusion and policy implications

Farmers' knowledge and perception of climate change allow policymakers to gain a profound understanding of the reality of climate change at the local level. However, evidence shows considerable gaps between local-level realities and agricultural policies as existing policies are developed at the national or regional levels without considering local conditions.

This study aims to investigate how farmers' perceptions and knowledge influence CSA adoption as an adaptation measure in response to climate change and variability in Southern Ethiopia. Farmers' decision-making process for adopting climate-smart agriculture practices requires more than one step. In the first stage, farmers need to be aware of and perceive climate change before responding to it. The Heckman probit sample selection model using a two-step approach was employed to analyze the data and correct for selectivity bias. Qualitative methods, such as FGDs and KIIs, were also applied to support and strengthen the model outputs.

The results indicate that most farmers perceived their local climate as changing, consistent with meteorological records of increasing temperature and decreasing rainfall trends across decades. In response to climate change impacts, various CSA practices have been adopted by smallholder farmers with the help of local extension agents and non-governmental organizations.

Farmers' perceptions of climate change and variability was significantly influenced by age of the household head, level of education of the household head, farming experience and access to climate information. Farmers adaptation to climate change through adoptions of CSA practices was significantly influenced by education, family size, gender, landholding size, farming experience, access to climate information, training received, social membership, livestock ownership, farm income and extension services. Additionally, farmers' farming experiences, education, gender, income, climate information, social group membership, risk-taking behavior, and extension services are key factors influencing CSA adoption. Maintaining feasible adaptation and mitigation investments using CSA practices and building the adaptation capacity of households is imperative. The study implies the need to support smallholder farmers' CSA practice and technology with various policy support initiatives, including credit and farm inputs subsidies, to improve farmers' aspiration for future economic opportunities.

The policy intervention to improve agricultural production and adopt appropriate CSA practices should consider reducing farmers' exposure to climate risks and alleviating farmers' difficulties while undertaking CSA. Thus, enhancing farmers' education, accurate climate information, and strengthening extension services are some policy measures that need to be taken to promote CSA uptake.

Overall, the finding of this study emphasizes the great importance of awareness and perception of climate change for adopting selected CSA practices enhancing farmers' aspirations of future opportunities and building climate-resilient sustainable agricultural productivity. Farmers need to focus and follow appropriate CSA practices and technologies to build their resilience to climate change and ensure sustainable agricultural productivity. The main scientific contribution of this paper is to show that farmers' knowledge and perception of climate change leads to the adoption of CSA practices, and this would increase the chances of CSA adoption.

Declarations

Author contribution statement

Abrham Belay: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Christopher Oludhe: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Alisher Mirzabaev: Contributed reagents, materials, analysis tools or data; Wrote the paper.

John W. Recha: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Zerihun Berhane: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Philip M. Osano: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Teferi Demissie: Analyzed and interpreted the data; Wrote the paper.

Lydia A. Olaka:Conceived and designed the experiments; Wrote the paper.

Dawit Solomon: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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