Climatic Change (2022) 174:21
https://doi.org/10.1007/s10584-022-03445-5

Access to climate information services and climate-smart agriculture in Kenya: a gender-based analysis

Marther W. Ngigi[1] · **Elijah N. Muange**[1]

Received: 25 March 2022 / Accepted: 2 October 2022

Abstract
Climate change is a significant threat to agriculture-related livelihoods, and its impacts amplify prevailing gender inequalities. Climate information services (CIS) are crucial enablers in adapting to climate change and managing climate-related risks by smallholder farmers. Even though various gender groups have distinct preferences, understandings, and uses of CIS, which affect adaptation decisions differently, there is little research on gender perspectives of CIS. This study employs a novel intra-household survey of 156 married couples to evaluate the gender-differentiated effects of CIS access on the adoption of climate-smart agriculture (CSA) technologies in Kenya. The findings reveal gender differences in access to CIS, with husbands having significantly more access to early warning systems and advisory services on adaptation. In contrast, wives had better access to weather forecasts. About 38% of wives perceived that CIS meets their needs, compared to 30% of husbands. As for CIS dissemination pathways, husbands preferred extension officers, print media, television, and local leaders, whereas wives preferred radio and social groups. Recursive bivariate probit analysis shows that trust in CIS, a bundle of CIS dissemination pathways, access to credit, and membership in a mixed-gender social group, affected access to CIS for both genders. Access to early warning systems and advisory services positively affected decisions to adopt CSA by both genders. Still, access to seasonal forecasts influenced husbands' decisions to adopt CSA but not wives. Besides, there were gender differences in how CIS affected each CSA technology based on gendered access to resources and roles and responsibilities in a household. It is necessary to disseminate CIS through gender-sensitive channels that can satisfy the needs and preferences of different gender groups to encourage the adoption of climate-smart technologies.

Keywords Climate information services · Climate-smart agriculture · Adaptation · Gender · Intra-household · Recursive bivariate probit

✉ Marther W. Ngigi
m_ngigi@mksu.ac.ke

[1] Department of Agricultural Sciences, Machakos University, P.O. Box 136-90100, Machakos, Kenya

1 Introduction

Climate change and variability remain major threats across sub-Saharan Africa (SSA), with adverse effects on agricultural productivity, farm incomes, food insecurity, and amplifying prevailing gender inequalities (UNDP 2017; Ofori et al. 2021). Drought and rising annual temperatures are prevalent climatic risks that impair rain-fed agricultural systems and jeopardize smallholder farmers' livelihoods (FAO et al. 2020; WMO 2021). With growing Africa's population predicted to reach 2.5 billion people by 2050, the continent's agriculture and food systems must undergo significant transformations to meet the increasing demand for high-quality food and nutrition while also addressing climate change, gender inequality, and environmental degradation (FAO et al. 2020). Increasing access to climate information services (CIS) to support the adoption of climate-smart agriculture (CSA) technologies is vital for managing climate risks and improving enabling ecosystem for CSA scaling (Born 2021).

CSA technologies are critical for addressing climate change and variability and their consequential effects. The technologies can help overcome the intertwined threats of food insecurity and climate change by increasing agricultural productivity, strengthening resilience, and lowering emissions (FAO 2013). Despite the potential benefits of CSA technologies, their widespread adoption is still low among African smallholder farmers (Barnard et al. 2015; Kurgat et al. 2020), with notably lower adoption rates among female farmers compared to their male counterparts (Chibowa et al. 2020; Tsige et al. 2020). Less than 30% of female farmers have embraced CSA technologies, compared to 70% of male farmers in Malawi (Chibowa et al. 2020). In Kenya, the adoption rate of individual CSA technologies is low, with less than 30% of farmers adopting agroforestry, 44% integrating crops with animals, and 15% using certified seeds. However, more than 80% of smallholder farmers have adopted at least one CSA technology (Andati et al. 2022; Musafiri et al. 2022). Smallholder farmers' main constraints to adopting CSA practices and technologies include biophysical, socio-economic, and software barriers like institutional, policy, willingness to invest, climate information, and gender-related inequalities (Barnard et al. 2015; Autio et al. 2021; Phiri et al. 2022). For instance, gender perspectives are crucial while analyzing the adoption of CSA because agricultural practices depend on social structures, gender roles, and cultural norms, in addition to the fact that women are active agents in climate change adaptation (Phiri et al. 2022). The main constraints preventing female farmers from adopting CSA technologies are high costs of inputs, lack of credit, and income and labor requirements (Chibowa et al. 2020).

Lack of access to CIS is a significant barrier to adopting CSA technologies by smallholder farmers (Autio et al. 2021). Access to CIS provides a promising conduit for scaling up and out CSA technologies. According to the World Meteorological Organization (WMO), science-based climate information is essential to strengthen resilience, support climate change adaptation, and improve sustainable livelihoods and development (WMO 2021). Timely provision of and access to climate information helps to lower the adverse impacts of climate change through promoting sufficient preparedness and informed decision-making by farmers, hence building resilience to climate change and variability (ECA 2021). Evidence suggests that access to CIS is a critical strategy for promoting the adoption of CSA technologies in Africa (Djido et al. 2021). Recent research shows that farmers can effectively plan their farming activities, such as planting dates, crop type and variety selection, and harvesting time, with access to seasonal forecast (Amegnaglo et al. 2017; Guido et al. 2020; Djido et al. 2021).

Different actors and institutions such as government agencies like the Kenya Meteorological Department (KMD), research institutions, international development agencies, academia, private sector entities, and non-governmental organizations (NGOs) provide CIS in Kenya. The main channels of CIS dissemination include newspapers, bulletins, radio, television, trained intermediaries, short messaging service (SMS), internet, mobile phone applications, digital platforms, farmer organizations, and agricultural extension officers (World Bank Group 2016). Despite the advancements in climate predictions and their potential benefits to farmers, the utilization of CIS in making decisions on the uptake of CSA technologies by farmers remains low in SSA. For instance, about 40% of smallholder farmers in Kenya and a small minority of farmers in Senegal use climate information to decide how to adapt to climate variability (Serra and McKune 2016; Muema et al. 2018).

Several studies have examined the effects of access to CIS on farmers' decisions to adapt to climate change, but the findings are generally mixed. A survey by Yohannis et al. (2019) found that using ICT tools like mobile phones and radio could enable communities, including women, to access localized agro-advisory and climate information that helps them improve their livelihood strategies. Similarly, Djido et al. (2021) found that in Ghana, access to weather and climate information services (WCIS) through mobile-based technologies improved the adoption of CSA technologies such as multiple cropping practices, water management, and pest-resistant crops. Conversely, Owusu et al. (2021) reported from their Ghana study that household heads' use of climate information had no significant effect on adopting any climate-smart technology. These studies show that farmers' use of climate information services may or may not affect a farmer's decision to adopt CSA technologies.

We complement the above studies by focusing on a gender viewpoint, because access to CIS often fails to consider gender-specific needs or use gender-sensitive dissemination channels. Evidence shows that female farmers do not have timely weather and climate information, which constrains their capacity to manage climate risk (Partey et al. 2020). A recent study by Alvi et al. (2021) shows that COVID-19-related lockdowns have exacerbated female farmers' lack of access to timely climate information, negatively affecting agricultural productivity. Besides, due to existing inequalities in access to and management of productive resources, financial services, community institutions, employment possibilities, advisory services, and CIS, women farmers are highly vulnerable to climate change and variability (FAO and World Bank 2017; Ngigi et al. 2017; Partey et al. 2020). Moreover, men and women are likely to have different needs for CIS. Diouf et al. (2019) showed that in Senegal, women demand information on the onset date of the rainy season and prefer climate information channeled through radio. Several studies have examined gendered access to climate information services (Diouf et al. 2019; Partey et al. 2020; Alvi et al. 2021). These studies have, however, focused on comparing male- and female-headed households or men and women with agricultural plots that often lack more nuanced gender perspectives on access to CIS. Further work by Al-Amin et al. (2019) revealed that husbands and spouses within the same households could have significantly different perceptions about climate change. Notwithstanding this revelation, there is limited empirical evidence on intra-household interplay in access to CIS, and CIS needs for men and women within the same household. Because household members hardly work as a unified production or consumption unit, intra-household research focusing on individual members is critical since they have distinct needs and access to resources, including CIS. Hence, the study uses a collective household model to capture the intra-household dynamics of access to CIS. This approach is more appropriate because spousal transfers of CIS is complex, each person has unique preferences regarding CIS and dissemination channels, allocation of

family resources and responds differently to policy initiatives (Alderman et al. 1995). This paper extends Ngigi et al. (2017) by demonstrating gender differences in using CIS and how different types of CIS influence decisions to adopt individual CSA technology.

This study fills the above research gap by assessing gendered access to CIS and its effects on the uptake of CSA technologies. The study employs a novel intra-household dataset of 156 married couples to answer the following questions: (i) What climate information services are available to husband and wife in the same household? (ii) Are there gender differences in preference to and trust in CIS dissemination channels? (iii) What factors influence access to CIS for husbands and wives? (iv) Do gender differences in access to CIS affect the adoption of CSA technologies? The WMO underscores the importance of improved provision, communication, and use of CIS to strengthen the resilience, productivity, and livelihoods of farmers of both genders (WMO 2021). Therefore, the findings of this study will aid in climate-related decision-making by assisting in the development of strategies and interventions for disseminating CIS suited to gender-specific needs and preferences.

The rest of the paper is organized as follows: "Section 2" provides an overview of the study's methodology, "Sections 3 and 4" present the results and discussions, and "Section 5" concludes by giving policy recommendations.

2 Methodology

2.1 Conceptual framework

We base our study on the conceptual framework shown in Fig. 1. The framework presents association pathways between CIS access and CSA adoption and their determinants. It illustrates that farmers' adoption of CSA technologies depends on access to CIS and other factors such as gender-related factors, household and farm characteristics, institutional factors like social capital, access to credit, extension services, and CSA technology-related variables (FAO and World Bank 2017; Chibowa et al. 2020; Andati et al. 2022). Further, access to CIS is not exogenous but is determined by a number of factors, several of which have also been reported to influence the uptake of CSA technologies (Ndavula and Lungahi 2018; Partey et al. 2020; Djido et al. 2021; Muita et al. 2021). According to these studies,

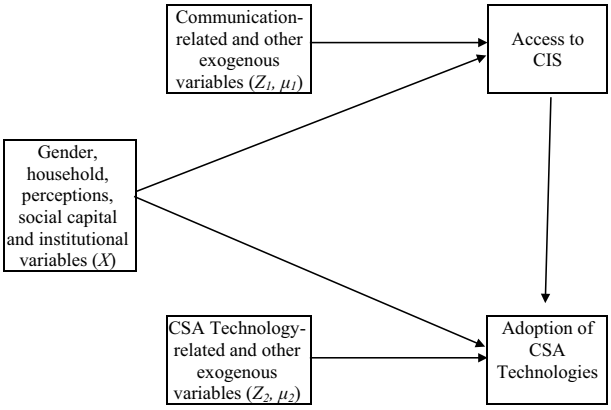

Fig. 1 A framework showing hypothesized association pathways between CIS access, CSA technology adoption, and their determinants

factors that influence the use of CIS include access to credit, perceptions about climate change, demography, gender, and access to communication technologies like telephone devices and radio.

2.2 Econometric framework

To operationalize the conceptual framework above, we used a regression approach to analyze the factors that influence both access to CIS and the adoption of CSA technologies. Our framework has two binary responses: one is the outcome variable (adoption of CSA technology), and the other is an endogenous explanatory variable (access to CIS). The regression model for the determinants of CSA technology adoption takes the form:

$$CSA_i = \alpha_1 + \gamma CIS_i + X_i'\delta_1 + Z_1'\delta_2 + \mu_1, \quad CSA_i = 1\left[CSA_i > 0\right] \tag{1}$$

where, for each farmer, i, CIS is the binary variable equal to 1 if the farmer accessed each category of CIS and zero otherwise; γ is a coefficient measuring the effect of access to CIS on decisions to adopt CSA technologies; X is a set of exogenous variables that drive CSA adoption; Z_1 is a set of CIS-related and other exogenous variables not captured by X; α_1 is a coefficient, while δ_1 and δ_2 are vectors of coefficients, to be determined by the model; and μ_1 is the error term.

The variable CIS in Eq. (1) can be expressed as:

$$CIS_i = \alpha_2 + X_i'\beta_1 + Z_2'\beta_2 + \mu_2, \; CIS_i = 1\left[CIS_i > 0\right] \tag{2}$$

where for each farmer, i, X is a set of exogenous variables that influence access to CIS; Z_2 is a vector of CSA technology-related and other exogenous variables not captured by X or Z_1; $\boldsymbol{\alpha}_2$ is a coefficient while β_1 and β_2 are vectors of coefficients to be estimated; and μ_2 is the error term. The variables included in the model are described in Table A1 in the supplemental material.

From our conceptual framework, we have demonstrated that access to CIS and adoption of CSA are influenced by a number of common variables. Hence, it is plausible to hypothesize that both CIS access and CSA adoption could as well be affected by some common unobserved factors, making μ_1 and μ_2 and CIS_i and μ_1 to be correlated. This means that the CIS_i variable in Eq. (1) could be endogenous, and the parameter γ estimated in Eq. (1) would be inconsistent due to omitted variable bias (Greene 2018).

To address this problem, Eqs. (1) and (2) were estimated using a joint maximum likelihood procedure that yields more consistent parameters than estimating separate probit models (Wooldridge 2010; Greene 2018). The procedure was performed using a recursive bivariate probit model that is characterized by a structural equation, where a binary outcome (adoption of CSA technology) is expressed as a function of a binary endogenous treatment variable (access to CIS) (Filippini et al. 2018). Where the outcome and treatment variables are binary, the recursive bivariate model is able to control for selection bias and endogeneity, unlike other econometric methods like the instrumental variable approach and two-stage least squares (Wooldridge 2010; Greene 2018).

The error term, $\mu = (\mu_1, \mu_2)$, of the model is presented as:

$$\frac{\mu_1}{\mu_2}|(X_1, X_2) \sim \mathcal{N}\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & \rho\\ \rho & 1\end{bmatrix}\right) \tag{3}$$

The joint distribution function of μ_1 and μ_2 in the recursive bivariate model, $\Phi_2(\mu_1, \mu_2, \rho)$, is assumed to be independent of (X_1, X_2) and consists of zero means, unit variances, and correlation coefficients ρ, generated from a standard bivariate normal distribution (Wooldridge 2010; Li et al. 2019). The model was estimated using a novel Stata user-written command, *rbiprobit*, version 1.0.0, with separate models for husbands and their spouses. Further, the recursive bivariate probit model was applied to each category of CIS, with the overall decision to adopt and for individual CSA technology.

2.3 Assessing the intra-household interplay

The paper examines the degree to which husband and spouse within the same household agree, or respond contrarily to questions about access to CIS, need for CIS, channels of CIS, and trust in sources of CIS. Hence, Cohen's kappa coefficient (k) analyzed the intra-household and inter-rater agreement of husband and wife. The kappa estimate uses dichotomous data to measure if the husband and wife had similar answers to questions about access, sources, and reliability of sources of CIS. The kappa statistic ranges from -1 to $+1$, where 1 indicates a perfect agreement between respondents, a value of -1 signifies agreement by chance, and 0 indicates no agreement (Viera and Garrett 2005; McHugh 2012). Besides, the t-test assessed the significance of the difference in the means for continuous variables. The z-test set the equality of proportions to test if the responses of the husband and wife were independent or differed significantly from each other.

2.4 Measurement of key variables

2.4.1 Climate information service

CIS involves the production, translation, dissemination, and use of climate information by individual and community users and their needs for decision-making (Carr et al. 2020). The service provides weather and climate information that farmers can use to address climate risks and consequences (World Bank Group 2016). It includes short-term weather forecasts, advisory services, long-term information on climate data and products, and appropriate information about technologies necessary to manage climate risks. Weather and seasonal climate forecasts involve the provision of forecasts before starting a farming season to support farmers in making informed decisions and adapting to climate variability. For CIS to be helpful and meet the users' needs, it must have desirable qualities. These qualities include availability, dependability, usability, credibility, authenticity, responsiveness, timeliness, and flexibility (WMO 2021). In this study, we are interested in determining access to CIS, if CIS meets the users' needs, channels for climate information dissemination, and the level of trust for various channels of climate information dissemination disaggregated by gender. A binary variable captured if farmers had access to four categories of CIS considered in this study, namely, weather forecasts, seasonal weather forecasts, early warning systems, and advisory services on CSA. A binary variable measured the channels of CIS and the preferred CIS dissemination channels by husbands and wives. A scale of one to five, ranging from strongly distrust to strongly trust, measured the level of trust in

various sources of CIS. Twelve ordinal statements on trust level in CIS were reduced into a score using nonlinear principal component analysis (NLPCA). The NLPCA was used for this study because it is more flexible than linear PCA and may be used to analyze both nominal and ordinal data (Linting and van der Kooij 2012).

2.4.2 Climate-smart agriculture

In the face of climate change, CSA technologies aid agricultural systems in promoting food security. CSA aims to increase agricultural productivity while improving resilience to climate-related risks and lowering agricultural emissions (FAO 2013). The study considered CSA in crop and livestock production adopted by husband and spouse either on individual plots or at the household level. For brevity, we generated a binary variable equal to one if the husband or spouse had adopted any CSA technology in agriculture (either crop or livestock production) and for each CSA technology, and zero otherwise. The crop climate-smart technologies considered were change in crop types and varieties, planting dates, increase land under production, crop rotation, water harvesting, irrigation, agroforestry, and soil conservation. Changing animal breeds, destocking, changing and diversifying feeds, supplementary feeds, and diversifying livestock portfolios are examples of climate-smart livestock technologies considered in this study.

2.5 Data

This paper leverages an intra-household dataset obtained in 2012 from four counties in Kenya. The sampled counties were Embu, Nakuru, Nyeri, and Siaya. The study used a multi-stage selection and purposive sampling approach to identify counties with diverse cultural and economic backgrounds, agroecological conditions, and climate change susceptibility. Households where couples were identified for interview were sampled using a random sampling approach. Hence, intra-household data was acquired by interviewing the husband and wife individually and simultaneously, with no opportunity for consultation. A random sample of 156 married couples was involved in the survey amounting to 312 respondents.

The database contains gender-differentiated and intra-household information on access to specific needs for CIS, access to production resources, individual characteristics, perceptions of climate change, and the uptake of CSA technologies. The survey questionnaire was cautiously pretested in a village in Embu County, which had similar economic and climate conditions to the targeted study sites. The questionnaire was revised to incorporate the concerns identified during the pretest. To adhere to research ethics and gender considerations, male and female research assistants interviewed husbands and their spouses. This allowed for the creation of a pleasant interview setting that ensured the correctness of the data obtained. Research assistants were trained to ensure quality and ethical data collection. Furthermore, before the interviews, the research assistants explained the purpose of the study and obtained verbal consent from the spouses.

The spouses interviewed had individual and household plots, hence having the autonomy to decide on production. However, the data did not distinguish whether CSA technologies were implemented on individual or household-level plots. The dataset indicates gender differences in access to and use of crucial resources that determine access to CIS and the adoption of CSA technologies. Table A1 in the supplemental material presents definitions, descriptive statistics, and gender differences of the variables.

3 Results

3.1 Gender analysis of access to and needs for CIS

Table 1 compares access to CIS between husbands and spouses within the same households. The results indicate that 63% of wives had access to weather forecasts, compared to 45% of husbands (Pearson $X^2 < 0.001$). This could be attributed to women's ability to access radio that mainly broadcasts weather forecasts to farmers easily. A higher proportion of husbands had access to early warning systems, particularly on droughts and floods, and also had access to advisory services on adapting to climate change compared to their spouses. The kappa statistics were insignificant for all CIS, meaning there was no agreement on access to CIS, which implies gender differences in access to CIS between spouses.

We further asked respondents whether CIS acquired through various dissemination pathways met their needs for climate change adaptation. Interestingly, 38% of wives indicated that climate information (CI) received met their needs, compared to 30% of husbands ($p < 0.10$). This implies that CI received by farmers could be inadequate. Hence, more information on how to adapt to changing climate and weather variability is required. CIS needs were significantly different between husbands and wives. More men reported requiring CI on rainfall patterns (25%), compared to 13% of wives. A higher percentage of wives needed CI on localized weather forecasts (12%) and the effects of climate change (8%) against 6% and 3% of husbands, respectively. Both husbands and wives stated that they need accurate weather information to guide them on when to begin planting and advisory services on appropriate adaptation strategies.

3.2 Gender analysis of CIS dissemination pathways

Table 2 shows that there were gender-specific preferences for different CIS dissemination pathways. Husbands mostly preferred receiving CIS through agricultural extension officers, print media, television, and local leaders. In contrast, radio and social groups were wives' most preferred channels for accessing CIS. Furthermore, husbands and spouses stated that the CIS conveyed by radio programs and extension officers significantly impacted their decision to adopt appropriate CSA technologies. For example, CIS influenced decisions to adopt drought-tolerant crop types and cultivars, soil and water management strategies, agroforestry, and other agricultural innovations. Trust in the information acquired through

Table 1 Gender differences in access to CIS

Climate information services	Overall (% yes)	Husbands (% yes)	Wives (% yes)	Difference in % point
Accessed at least one CIS	87.50	88.39	87.18	1.21
Accessed weather forecasts	54.17	44.87	63.46	-18.59^{***}
Accessed seasonal forecasts	28.21	26.28	30.13	−3.85
Accessed early warning systems	32.37	38.46	26.28	12.18^{**}
Received advisory services on adaptation	33.33	42.95	23.72	19.23^{***}
CIS meets the need of farmers	34.29	30.12	38.46	-8.3^{*}
N	312	156	156	

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$, following a *z*-test for equality of proportions

Table 2 Gender differences in preferences for CIS dissemination pathways

Dissemination pathway	Overall (% yes)	Husbands (% yes)	Wives (% yes)	Difference in % point
Radio	75.00	68.59	81.41	−12.82**
Extension officers	31.41	42.31	20.51	21.79***
Television	19.73	22.15	17.31	4.84*
Social groups	16.03	12.18	19.87	−7.69**
Other farmers	6.73	7.05	6.41	0.64
Local leaders	3.21	5.13	1.28	3.85**
Printed media—news paper	2.89	5.13	0.64	4.49*
Field days	1.28	1.92	0.64	1.28
NGOs	0.32	0.64	0.00	0.64
Number of sources of CIS (mean)	1.88	1.91	1.85	0.06
Trust score on sources of CIS (mean)	0.68	0.65	0.70	−0.05**
N	312	156	156	

*$p<0.1$, **$p<0.05$, ***$p<0.01$, following a *z*-test for equality of proportions and *t*-test for difference in means

different pathways could also influence the adoption of CSA technologies. Results show that wives had a higher trust index (0.70) on CIS dissemination pathways than husbands (0.65) ($p<0.05$). Wives reported that CIS from extension officers and social groups was more reliable, while husbands indicated that CIS from university scientists and Kenya meteorologists was more truthful. The kappa results show that both husbands and spouses agreed that the CIS obtained from farmer groups, printed media, radio programs, and extension agents was relevant and trustworthy (p value <0.10).

3.3 Adoption of CSA strategies, by use of various CIS among husbands and wives

Table 3 compares adoption rates between those who had accessed CIS and those who had not, for husbands and wives.

The findings show that uptake of CSA technologies was higher for farmers who accessed CIS than for farmers who did not access it. Among husbands, adoption of CSA was significantly higher for those who had accessed seasonal forecasts, early warning systems, and advisory services on adaptation, than those who had not accessed these services. On the other hand, the adoption of CSA was higher for wives who had accessed early warning systems and advisory services on adaptation than those who had not. Adoption of CSA by both wives and husbands did not differ significantly by access to weather forecast information.

Table 4 presents the adoption of each CSA technology distinguished by gender and access to CIS. Both husbands and wives who had access to advisory services were more likely to adopt agroforestry, change crop varieties, and reduce the number of livestock (destocking). A higher proportion of husbands who had access to advisory services on adaptation embraced crop rotation, soil conservation, change in animal breeds, and diversified livestock. In contrast, wives with access to advisory services were likelier to change planting dates but less likely to adopt soil conservation practices.

Table 3 Access to CIS and adoption of CSA, by gender

Variable		CIS accessed			
		Weather forecasts	Seasonal forecasts	Early warning systems	Advisory services
Uptake of CSA (% sample)					
Husbands	Yes	71.43	85.37	90.00	91.05
	No	80.23	73.04	67.71	65.17
	Difference	−8.80	12.32*	22.29***	25.88***
Wives	Yes	84.84	85.11	90.24	97.23
	No	84.21	84.40	82.61	80.67
	Difference	0.6	0.7	7.64*	16.63**
Whole sample	Yes	81.81	85.57	90.01	93.27
	No	79.29	78.57	75.83	74.03
	Difference	2.53	6.65*	14.27***	19.23***

*$p<0.1$, **$p<0.05$, ***$p<0.01$, following a z-test for equality of proportions

Supplemental Tables A2 and A3 illustrate that husbands' and wives' access to other kinds of CIS influenced the uptake of each CSA technology in different ways. Husbands' and wives' access to early warning systems led to changing crop varieties. It is linked to husbands' decisions to adopt water harvesting strategies, crop rotation, destocking, livestock diversification, and increased land under crop production. In contrast, a higher proportion of wives who had access to early warning changed crop types and planting dates but were less likely to adopt soil conservation practices. Notably, access to weather forecasts led to a lower proportion of husbands changing crop varieties and types, adopting crop rotation, destocking, and livestock diversification strategies.

3.4 Econometric results on factors influencing access to CIS by husbands and wives

Table 5 presents the findings of the second stage of recursive bivariate probit models on gendered factors determining access to CIS (models 1–8). Results show that age negatively influenced access to seasonal forecasts by women but not by men. The younger women were more likely to seek out climate information than older women. The findings on the influence of levels of education on the use of climate information services were mixed. Years of schooling negatively influenced access to early warning systems by husbands and access to appropriate advice on adaptation by wives but positively influenced access to weather forecasts by wives.

Access to multiple CIS dissemination pathways positively influenced access to CIS by both husbands and wives. For the husbands, this influence was positive for weather forecasts, early warning systems, and advisory services but insignificant for seasonal forecasts. At the same time, the effect was significant for wives for weather forecasts and early warning systems. This implies the need to disseminate CI through various platforms that may fit recipients' convenience, conditions, and preferences. The level of trust in CI was associated with access to seasonal forecasts, early warning systems, and advisory services by husbands and seasonal forecasts and advisory services by wives. This implies that farmers' perception of CIS's reliability could influence CI access consequently, adaptation to climate change.

Table 4 Gender analysis of access to CIS and adoption of individual CSA technology

CSA	CSA technologies			Advisory services on CSA					
	Husbands (% yes)	Wives (% yes)	Difference (%)	Husbands			Wives		
				Yes (%)	No (%)	Difference (%)	Yes (%)	No (%)	Difference (%)
Change crop varieties	36.54	40.48	−3.95	49.25	26.97	22.29***	56.76	35.29	21.46***
Change crop types	14.74	19.23	−4.49	16.42	13.48	2.93	18.92	19.33	−0.41
Change plating dates	14.10	13.46	0.64	14.93	13.48	1.44	18.92	11.76	7.15**
Increase under production	1.28	6.41	−5.13*	1.49	1.12	0.37	2.70	7.56	−4.86
Crop rotation	11.54	14.74	−3.21	16.42	7.87	8.55**	16.22	14.29	1.93
Water harvesting	7.69	7.05	0.64	2.99	4.49	−1.51	2.70	0.84	1.86
Irrigation	2.56	7.05	−4.49*	1.49	3.37	−1.88	8.11	6.72	1.39
Soil conservation and management	10.90	17.31	−6.41*	17.91	5.62	12.29***	5.41	21.01	−15.60***
Agroforestry	16.03	8.33	7.69*	25.37	8.99	16.38***	13.51	6.72	6.79*
Change animal breeds	12.82	10.90	1.92	19.40	7.87	11.54**	8.11	11.76	−3.66
Destocking	23.72	18.59	5.13	29.85	19.10	10.75**	24.32	16.81	7.52**
Diversity feeds	22.44	18.59	3.85	23.88	21.35	2.53	21.62	17.65	3.97
Change feeds	0.64	1.28	−0.64	0.00	1.12	−1.12	0.00	1.68	−1.68
Supplementary feeds	3.85	5.77	−1.92	5.97	2.25	3.72	8.11	5.04	3.07
Diversify livestock portfolio	10.90	14.74	−3.85	16.42	6.74	9.68**	13.51	15.13	−1.61
N	156	156		67	89		37	119	

*$p<0.1$, **$p<0.05$, ***$p<0.01$, following a *z*-test for equality of proportions

Table 5 Factors influencing access to CIS disaggregated by gender

Variable	*Husbands' model*				*Wives' model*			
	Weather forecasts	Seasonal forecasts	Early warning systems	Advisory services	Weather forecasts	Seasonal forecasts	Early warning systems	Advisory services
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Age in years	−0.001	−0.006	−0.013	0.003	−0.006	−0.032**	−0.011	−0.013
	(0.010)	(0.010)	(0.009)	(0.009)	(0.012)	(0.013)	(0.013)	(0.015)
Years of schooling	−0.023	0.023	−0.078*	0.038	0.089**	−0.030	−0.059	−0.084*
	(0.033)	(0.045)	(0.041)	(0.062)	(0.040)	(0.046)	(0.037)	(0.045)
Number of CIS pathways	0.259**	0.085	0.428***	0.321***	0.533***	0.148	0.272**	0.003
	(0.146)	(0.120)	(0.117)	(0.110)	(0.143)	(0.128)	(0.119)	(0.124)
Trust index of CIS	−0.827	1.247*	1.446**	2.615***	0.072	1.906**	0.301	3.562***
	(0.5361)	(0.662)	(0.604)	(0.662)	(0.633)	(0.749)	(0.614)	(1.014)
Credit access	−0.739***	−0.366	1.194***	0.765***	−0.826***	−0.016	0.891***	1.420***
	(0.240)	(0.268)	(0.274)	(0.259)	(0.267)	(0.249)	(0.256)	(0.322)
Belong to a mixed gender group	−0.440	0.734**	0.133	0.477**	−0.101	0.518	0.283	0.591**
	(0.273)	(0.328)	(0.311)	(0.250)	(0.240)	(0.315)	(0.231)	(0.279)
Ln total income	−0.043	−0.327*	0.310**	−0.224	0.089	0.014	−0.138	0.197
	(0.163)	(0.194)	(0.182)	(0.180)	(0.151)	(0.201)	(0.148)	(0.175)
Interaction of perception of rainfall and temp	−0.399*	−0.127	0.686**	0.199	0.397	0.038	−0.250	−0.026
	(0.227)	(0.244)	(0.268)	(0.225)	(0.258)	(0.376)	(0.237)	(0.292)
Household size	−0.039	0.014	0.014	0.063	−0.050	−0.127**	−0.033	−0.104*
	(0.049)	(0.058)	(0.056)	(0.053)	(0.052)	(0.063)	(0.061)	(0.062)
Distance to the market	0.029	0.019	−0.015	−0.012	0.034	0.002	−0.028	0.082
	(0.023)	(0.024)	(0.027)	(0.031)	(0.039)	(0.026)	(0.031)	(0.056)
Total TLU	−0.008	−0.039*	0.053	−0.040	−0.029	0.013	0.018	0.010
	(0.036)	(0.036)	(0.040)	(0.037)	(0.026)	(0.027)	(0.028)	(0.027)

Table 5 (continued)

Variable	*Husbands' model*				*Wives' model*			
	Weather forecasts	Seasonal forecasts	Early warning systems	Advisory services	Weather forecasts	Seasonal forecasts	Early warning systems	Advisory services
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Household asset index	−1.079	−0.427	−0.259	0.470	0.222	−1.451	0.557	−1.161
	(1.39)	(1.321)	(1.468)	(1.622)	(1.104)	(0.998)	(0.929)	(1.200)
Nyeri	0.002	−0.006	0.191	−0.284	−0.073	−0.799**	−0.132	−0.011
	(0.342)	(0.329)	(0.398)	(0.326)	(0.321)	(0.371)	(0.339)	(0.397)
Siaya	0.162	−0.098	0.245	0.167	0.420	−1.558***	−0.356	−0.664
	(0.410)	(0.402)	(0.450)	(0.352)	(0.379)	(0.575)	(0.369)	(0.517)
Embu	−0.303	−0.161	−0.017	−1.454***	−0.821*	−1.646***	0.923**	−1.321**
	(0.499)	(0.432)	(0.462)	(0.463)	(0.492)	(0.457)	(0.460)	(0.654)
Constant	1.959	2.783	−5.144**	−1.397	−1.439	1.523	0.565	−4.438*
	(2.036)	(2.439)	(2.119)	(2.224)	(1.851)	(2.402)	(1.886)	(2.339)
N	156	156	156	156	156	156	156	156

Standard errors in parentheses $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

Access to credit had mixed findings: while it positively influenced access to early warning systems and advisory services, it negatively affected access to weather forecast information for both husbands and wives. Farmers with higher incomes, primarily men, were more likely to access early warning information. Access to credit and income are essential resources to improve the ability to acquire necessary platforms like radios, mobile phones, and TVs that increase access to CIS, improving farmers' adaptive capacity. Further findings show that belonging to a mixed-gender social group positively influenced access to seasonal forecasts for husbands and advisory services for both husbands and wives. This implies that such social groups could provide a platform for men and women to interact and share climate information, improving CIS access.

Household size negatively influenced wives' access to seasonal forecasts and advisory services. This could imply that a larger family size provides an opportunity for sharing climate information, but with the possibility of misinformation and inappropriate adaptation information among members or women with a larger family size become too preoccupied with family issues, limiting their interaction with CIS platforms. Compared to Nakuru County, male farmers in Embu County were less likely to access advisory services on adaptation. Females were more likely to access early warning systems information but less likely to access weather and seasonal weather forecasts and advisory services on adaptation options. Female farmers in Siaya and Nyeri counties were less likely to use seasonal forecasts than female farmers in Nakuru County. These findings point to geographical variations in CIS access, perhaps due to differences in climatic conditions across the counties.

3.5 Econometric results on the effects of CIS on the adoption of CSA technologies

Table 6 shows the results of the effects of access to CIS on the adoption of CSA technologies that correspond to the first stage of the recursive bivariate probit model (models 9–16). Results for the control variables were omitted from Table 6 for brevity but are available upon request. The findings show that early warning systems and advisory services significantly and positively influenced husbands' and wives' uptake of CSA technologies. Access to seasonal forecasts positively affected the uptake of CSA technologies by husbands but had no significant effect on wives' decisions to adopt CSA technologies. Contrastingly, access to weather forecast information negatively impacted husbands' decisions to adopt CSA technologies. This could be because weather information is not timely and reliable, as reported by the farmers. Because husbands had greater access to more CIS diffusion pathways than wives, this favorably influenced their decisions to embrace CSA technology. Wives' trust in various sources of climate information had a positive effect on their decision to adopt CSA but did not affect their husbands' CSA technology adoption decision. This could be due to wives' higher level of trust in the sources of CIS than husbands', which could have led to a positive perception of climate information, consequently, their decisions to adopt CSA technologies.

Tables A4 and A5 in the supplemental material present the effect of CIS on individual CSA for husbands and wives, respectively. The findings point to gender differences in how different categories of CIS affect CSA adoption. Access to early warning negatively affected wives' decisions to change crop varieties and types, adopt crop rotation, soil management, and practice agroforestry, whereas it had a positive effect on husbands' decisions to change crop types and varieties, change planting dates, implement crop rotation, soil management, diversifying livestock feeds, and livestock portfolio. Access to advisory services on adaptation positively affected decisions to change crop varieties and types, change

Table 6 Effects of access to CIS on adoption of CSA technologies

CIS variable	*Husbands' model*				*Wives' model*			
	CSA technologies				CSA technologies			
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Weather forecasts	−1.701** (0.845)				−1.231* (0.712)			
Seasonal forecasts		1.755*** (0.207)				1.542 (1.341)		
Early warning systems			2.064*** (0.248)				1.678*** (0.287)	
Advisory services				2.212*** (0.340)				2.075** (0.810)
Number CIS pathways	0.442*** (0.138)	0.241** (0.129)	0.038 (0.082)	0.010 (0.107)	0.233 (0.182)	0.072 (0.169)	0.040 (0.111)	−0.031 (0.138)
Trust index on CIS	0.317 (0.878)	0.534 (0.474)	0.082 (0.463)	−0.555 (0.522)	2.020*** (0.784)	0.916 (2.641)	2.026*** (0.643)	1.501* (0.880)
Other control variable included	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.527 (2.503)	−2.022 (2.045)	2.885 (1.762)	0.057 (2.096)	−2.841 (2.397)	−4.038 (2.644)	−3.310 (2.336)	−3.261 (2.436)
N	156	156	156	156	156	156	156	156

Standard errors in parentheses $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

animal breeds, destock, diversify animal feeds, and diversify livestock portfolios for both husbands and wives. Access to weather and seasonal forecasts also had mixed effects on how they influenced decisions to adopt different CSA technologies. This could suggest that male and female farmers have different understandings of the CIS.

Results on factors influencing the adoption of each CSA technology for husbands and wives, a case of the advisory services model, are shown in Tables A6 and A7 in the supplemental material. The findings provide evidence of gender differences in the variables influencing decisions to adopt each CSA technology. The years of schooling of husbands positively influenced the adoption of various CSA technologies, such as a change in crop types and crop rotation. In contrast, it influenced changes in crop varieties for wives. Access to credit positively affected wives' decisions to switch to different crop types and diversify livestock portfolios while negatively impacted husbands' decisions to diversify livestock and adopt soil conservation strategies. The husbands' age negatively affected the decision to change crop varieties. In contrast, the wives' age positively affected the decision to switch crop varieties and destocking but negatively impacted change in crop types and soil conservation practices. Membership in a mixed-gender group positively affected adopting agroforestry and crop types for wives, as well as crop rotation and soil conservation practices. Household size negatively influenced wives' decisions to change crop types but positively affected husbands' decisions to change crop types and adopt agroforestry. Women with larger family sizes become preoccupied with family issues, making them reluctant to adopt labor-intensive technologies like agroforestry and soil management measures. Total TLU positively influenced the husbands' decision to change animal breeds, who own a more considerable percentage of livestock, especially cattle and larger livestock.

4 Discussion

This study expands the growing evidence on the role of gendered access to CIS in improving the uptake of CSA technologies. It illustrates the necessity of moving away from a unitary agricultural household model toward a model that focuses on individuals within the household. This is because it is usually a norm that household members have diverse preferences, needs, and budgetary restrictions and differ in control over resources.

Descriptive statistics point to differences in CIS access, dissemination pathways, and whether CIS met the needs of husbands and spouses within the same households. Wives had more access to weather forecasts, while a higher percentage of husbands had access to early warning information and advisory services. CIS needs were significantly different between husbands and wives. Husbands indicated that they need CIS on rainfall patterns and wives on local-specific weather forecasts and effects of climate change. Our findings resonate with those of Diouf et al. (2019) in Senegal, who found that men had more access to CIS, but both men and women required timely forecast information, such as the onset of the rainy season. To cope with unpredictable climate risks, Muita et al. (2021) discovered that farmers in Kenya require sub-seasonal and seasonal forecasts with reliable information on rainfall onset dates and distribution. The study also found significant gender-specific preferences in CIS dissemination pathways where husbands preferred receiving climate information through agricultural extension officers, print media, television, and local leaders, whereas the wives mainly preferred radio and social groups. Radio programs and extension officers were most influential on husbands' and wives' decision-making on the uptake of CSA technologies. Our findings are partly consistent with those of Henriksson

et al. (2021), who found radio the preferred means to communicate climate information, particularly weather forecasts, by both men and women farmers, but accessing forecasts through knowledge brokers was preferred mainly by women in Malawi. Diouf et al. (2019) similarly found that in Senegal, a higher percentage of women (46%, compared to 39% of men) prefer rural radio programs as the primary channel to access CIS. Evidence points out that local radio stations that use regional dialects play a vital role in disseminating local-specific and up-to-date weather and climate information to farmers, helping them make timely adaptation decisions. Yohannis et al. (2019) found that community radios help farmers access real-time and relevant local-specific climate information such as weather, seasonal forecasts, and agro advisories. However, Gumucio et al. (2018) suggest that child-care and household responsibilities could hinder women's attentiveness and ability to listen to radio programs, hence missing vital CIS. In such scenarios, repetitive radio broadcast programs could help reach many women farmers. In Malawi, mostly male farmers with higher education levels prefer accessing forecasts through the internet and mobile phones (Henriksson et al. 2021). This study found that wives preferred receiving CIS through social groups while being a member of a mixed-gender group influenced access to CIS for both husbands and wives due to the broader networks in such groups. This is because social networks, groups, and producers' organizations disseminate CIS to farmers, improving adaptive capacity, particularly for women farmers (Diouf et al. 2019). Furthermore, men preferred acquiring CIS through print media like newspapers, which may be explained by men having more years of schooling than women, as also reported by Henriksson et al. (2021).

Understanding the prerequisites across heterogeneity regarding gender and other factors is crucial to designing effective CIS communication and dissemination strategies and interventions. The study found gendered differences in factors influencing access to CIS due to inequalities in socio-economic characteristics. Perception of climate change influenced husbands' access to CIS, considering gender differences in perception of climate change. Contrary, Diouf et al. (2019) suggested that willingness to act against the effects of climate change influenced access to CIS by women. The age of the farmers influenced access to CIS by women, whereby younger women were more likely to access CIS. Our findings also indicate that high-income farmers, primarily men, were more likely to access and use CIS. Partey et al. (2020) similarly found that in Ghana, financial resources influenced access to CIS by men, enabling them to purchase mobile phones that facilitated easy access to CIS. The results indicate that both men and women require accurate CIS. While wives had a higher index of trust in CIS sources, perceptions of reliability and the level of trust in the CIS influenced access to the CIS by both husbands and wives. Farmers' high trust level in the CIS is linked to more accurate climate information, implying that forecasts play out as predicted. These results resonate with recent studies that have shown that the use of CIS requires that users perceive that information as reliable, accurate, and logical (Tembo-Nhlema, et al. 2019; Henriksson et al. 2021) and be disseminated before the agricultural season, preferably through communication channels that the users deem pertinent (Tall et al. 2018). Amegnaglo et al. (2017) found that farmers in West Africa needed precise seasonal forecasts provided at least two months before the onset of rains. Besides, both husbands and wives reported that weather forecasts are not accurate and dependable, which was confirmed by the finding that weather forecasts were negatively associated with adoption decisions by men. The study by Muita et al. (2021) resonates with our conclusions that farmers' perceptions of information influenced the choice of CI, while lack of trust, precision, and relevance of CI results in low use of information by farmers in Kenya, but their study overlooked gender perceptive of CIS. However, because there is inherent uncertainty

in climate information, events might not always turn out exactly as projected (Tall et al. 2018). Farmers' access to different CIS dissemination pathways influenced access to CIS by men and women. Access to ICT tools such as radio, TV, short messages through mobile phones, agricultural extension officers, participation in social groups, and active participation of NGOs in disseminating adaptation practices and climate information promoted uptake and use of CIS by farmers (Mwaniki et al. 2017; Ndavula and Lungahi 2018; McKune et al. 2018; Muita et al. 2021). Kumar et al. (2021) found that co-production of CIS with farmers and a bundle of communication that integrated forecast visualization, face-to-face interaction, printed media, and a smartphone app improved the uptake of CIS by farmers in the Bengal Delta.

Evidence points to difficulties in examining the extent to which using CIS influences farmers' decision-making (Tall et al. 2018). To explore the effects of CIS, we focused on the outcomes of behavioral changes in adaptation decisions, i.e., the overall decision to adapt CSA and adopt individual CSA practices, such as changes in crop varieties and types and changes in plating time. Both descriptive and econometric results point to gender differences in how access to CIS affects the decision to adapt and adopt specific CSA technology. Access to early warning systems and appropriate advice on climate change adaptation had the highest effects on husbands' and wives' uptake of CSA technologies, while access to seasonal forecasts positively affected the uptake of CSA technologies by husbands only. Access to different kinds of CIS influenced the uptake of specific CSA technologies among husbands and wives. For example, wives who had received advisory services increased their capacity to change crop varieties and types, change animal breeds, and diversify animal feeds and livestock portfolios. Climate services help farmers make informed decisions to improve their food security, yield, and income and acquire resources to invest in CSA technologies. Farmers who receive CIS increase their capacity to understand and adopt CSA (Born 2021).

Past evidence on the role of CIS and CSA adoption indicates mixed findings and conclusions. For instance, Chiputwa et al. (2021) reported mixed results whereby seasonal forecasts increased the use of improved seed, fertilizers, and manure but lowered the adoption of crop diversification. A recent study by McKune et al. (2018) found that in Kenya, CIS helped farmers make changes in farming operations without significant differences between men and women. However, there was no direct association between using CIS, adopting CSA practices, and food security. Roudier et al. (2012) found that decadal and seasonal forecasts induced adaptation decisions of millet farmers, making them adopt various millet cultivars, multiple fertilization, and different sowing dates. Chiputwa et al. (2021) found that weather and climate information increased the production of higher-value crops, which improved the income and livelihoods of farmers in Senegal. Kumar et al. (2021) found that weather forecasts helped farmers make strategic crop and livestock production decisions like better timing of inputs application that increased agricultural systems' profitability. In Ghana, Djido et al. (2021) found CIS increased the adoption rates of CSA practices such as pest-resistant crops, water management strategies, and multiple cropping practices. Contrarily, Owusu et al. (2021) found no significant impact of CIS on farmers' decision to adopt CSA technologies. This study adds to our understanding of how CIS promotes specific CSA technology and varies across male and female farmers.

Lastly, the econometric findings suggest gendered factors influencing decisions to adopt specific CSA. While these results focused on socio-economic and institutional factors, a keen look suggests that gendered roles, responsibilities, control over resources, and labor allocation could also affect CSA adoption. Access to credit and age positively affected wives' decisions to switch to different crop types and diversify livestock portfolios, while

household size negatively affected wives' adoption of different crop types. A larger household size could imply added responsibility to a woman in a household on family issues like food preparation and (child) care responsibility. Even with access to advisory services on adaptation, women were still reluctant to adopt labor-demanding CSA technologies like soil conservation and agroforestry. In Kenya, agroforestry is predominantly the men's responsibility, who also enjoy better land rights than women. CSA technology adoption also depends on diverse gendered roles in producing and distributing agroforestry benefits (Schürmann et al. 2020). Besides, amidst the gender gap in access to productive resources, women still play an important role in four pillars related to food security, more so in many aspects of crop production. Hence, women may be reluctant to change crop types or adopt any CSA technology before they are guaranteed of food security.

5 Conclusion and policy implications

This study evaluates the differential effects of CIS access on the adoption of CSA technologies between married couples. This study found significant differences in CIS access, means of access, perceptions, and needs between husbands and spouses within the same household. Wives had more access to weather forecasts, while a higher proportion of husbands had access to early warning information and advisory services on adaptation. CIS needs were significantly different between husbands and wives, whereby men needed information on rainfall patterns and women on local-specific weather forecasts and effects of climate change. There were significant gender-specific preferences for CIS dissemination pathways, whereby husbands preferred receiving CIS through agricultural extension officers, print media, television, and local leaders. In contrast, the radio and social groups were the most preferred channels for receiving CIS by wives. The study concludes there are gendered differences in factors influencing access to CIS due to inequalities in socio-economic characteristics and perceptions. Income and perception of climate change influenced husbands' access to CIS, while age, education level, household size, and agroecological regions influenced wives' access to CIS. Trust in CIS, access to a bundle of CIS dissemination pathways, access to credit, and membership in a mixed-gender group influenced access to CIS for both husbands and wives, while access to and use of CIS significantly affected the uptake of CSA technologies among both genders. Further, access to early warning systems and advisory services had the highest effects on husbands' and wives' uptake of CSA technologies. In addition, access to seasonal forecasts positively affected CSA's adoption by husbands but negatively impacted wives' decisions. In contrast, access to weather forecasts was negatively associated with husbands' decisions to adopt CSA technologies.

These findings bring out the need to create synergies to improve access to CIS and CSA adoption. There is a need to tailor the CIS to meet the needs and preferences of men and women. Moreover, CIS ought to be channeled through gender-sensitive communication pathways that can also meet the needs of both male and female farmers. Radio, social groups, and producer organizations could be used to communicate CIS, training, and support to women farmers, whereas agricultural extension services, TVs, and local leaders can be made more women-friendly to reach more female farmers. Amid evolving digital innovations, ICT-based channels like mobile phones, smartphone apps, and social media could increase the likelihood of women accessing and using essential CIS. The timing of communicating CIS should align with men's and women's livelihoods, societal engagements, roles, and responsibilities, where multiple radio or TV broadcasting, repetitive

messaging, and social group meetings could increase access to CIS by both genders. More so, there is a need to use a combination of communication pathways to promote access and use of CIS by men and women farmers. In addition, there is a need to consider gender-related constraints to accessing CIS and adoption of CSA, like the low literacy of women, while designing CIS and CSA strategies and interventions. For instance, technical CIS and CSA information could be simplified using local dialects, short videos, and visualization to reach out to more female farmers. Gender-related factors like access to credit for wives, engagement in mixed gender social groups and access to multiple information dissemination pathways, considerations of gender roles and responsibilities, and property rights could improve adoption rates of specific CSA technology.

Further research should evaluate the spillover effects of access to CIS within a household and how it affects adaptation behavior. Moreover, research should explore if CIS impacts crop productivity, food security, and income, which have received relatively little attention.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10584-022-03445-5.

Acknowledgements The authors would like to acknowledge financial support from the Federal Ministry for Economic Cooperation and Development (BMZ), Germany, under the project "Enhancing Women's Assets to Manage Risk under Climate Change: Potential for Group–Based Approach" through the Center for Development Research (ZEF).

Author contribution Study conception and design, data collection, analysis, and writing of the first draft were performed by Marther W. Ngigi. Elijah Muange did the methodology, review of the manuscript, and proofreading. All authors have read and approved the final manuscript.

Funding This work was supported by the Federal Ministry for Economic Cooperation and Development through the Center for Development Research (ZEF).

Data availability The datasets generated during and/or analyzed during the current study are not publicly available due to individual privacy, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The survey involved human participants who were married couples. The researchers obtained verbal consent before the interviews. We also adhered to gender ethics and norms where we aligned male research assistants to interview the male respondents and female research assistants to interview spouses. We have also declared that there are no conflicts of interest among the authors.

Consent for publication All authors read and approved the final manuscript. The authors are willing to sign a written formal consent before the publication of the manuscript.

Competing interests The authors declare no competing interests.

References

Al-Amin AKMA, Akhter T, Islam AH, Jahan H, Prodhan MH, Mainuddin M, Kirby M (2019) An intra-household analysis of farmers' perceptions of and adaptation to climate change impacts: empirical evidence from drought-prone zones of Bangladesh. Clim Chang 156:545–565. https://doi.org/10.1007/s10584-019-02511-9

Alderman H, Chiappori P, Haddad L, Hoddinott J, Kanbur R (1995) Unitary versus collective models of the household: is it time to shift the burden of proof? World Bank Res Obs 10(1):1–19

Alvi M, Barooah P, Saini S (2021) Women's access to agriculture extension amidst COVID-19: insights from Gujarat, India and Dang, Nepal. Agric Syst 188. https://doi.org/10.1016/j.agsy.2020.103035

Amegnaglo CJ, Anaman KA, Mensah-Bonsu A, Onumah EE, Amoussouga GF (2017) Contingent valuation study of the benefits of seasonal climate forecasts for maize farmers in the Republic of Benin, West Africa. Clim Serv 6:1–11. https://doi.org/10.1016/j.cliser.2017.06.007

Andati P, Majiwa E, Ngigi M, Mbeche R, Ateka J (2022) Determinants of adoption of climate smart agricultural technologies among potato farmers in Kenya: does entrepreneurial orientation play a role? Sust Tech Entrep 1(2):100017. https://doi.org/10.1016/j.stae.2022.100017

Autio A, Johansson T, Motaroki L, Minoia P, Pellikka P (2021) Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya. Agric Syst 194(December):103284. https://doi.org/10.1016/j.agsy.2021.103284

Barnard J, Manyire H, Tambi E, Bangali S (2015) Barriers to scaling up/out climate smart agriculture and strategies to enhance adoption in Africa. Forum for Agricultural Research in Africa, Accra. https://library.faraafrica.org/2021/01/19/barriers-to-scaling-up-out-climate-smart-agriculture-and-strategies-to-enhance-adoption-in-africa-2/

Born L (2021) Climate services supporting the adoption of climate smart agriculture. Potential linkages between CSA adoption and climate services use. CGIAR Info Note. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://cgspace.cgiar.org/bitstream/handle/10568/117328/InfoNote_LornaBorn.pdf

Carr ER, Goble R, Rosko HM, Vaughan C, Hansen J (2020) Identifying climate information services users and their needs in Sub-Saharan Africa: a review and learning agenda. Clim and Dev 12(1):23–41. https://doi.org/10.1080/17565529.2019.1596061

Chibowa TK, Synnevag G, Maonga B, Mainje M (2020) Gender differentiation in the adoption of climate smart agriculture technologies and level of adaptive capacity to climate change in Malawi. In: Singh BR, Safalaoh A, Nyambilila AA, Eik LO, Sitaula BK, Lal R (eds) Climate impacts on agricultural and natural resource sustainability in Africa. Springer International Publishing, Cham, pp 507–26. https://doi.org/10.1007/978-3-030-37537-9_29

Chiputwa B, Blundo CGM, Steward P, Andrieu N, Ndiaye O (2021) Co-production and uptake of weather and climate services: evidence of welfare impacts among farmers in Senegal using a dynamic panel data approach, CCAFS working paper no. 355. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCA). https://cgspace.cgiar.org/handle/10568/108054. Accessed 27 Jan 2022

Diouf NS, Ouedraogo I, Zougmoré RB, Ouedraogo M, Partey ST, Gumucio T (2019) Factors influencing gendered access to climate information services for farming in Senegal. Gender Tech Dev 23(2):93–110

Djido A, Zougmoré RB, Houessionon P, Ouédraogo M, Ouédraogo I, Diouf NS (2021) To what extent do weather and climate information services drive the adoption of climate-smart agriculture practices in Ghana? Clim Risk Manag 32. https://doi.org/10.1016/j.crm.2021.100309

ECA (2021) Private sector engagement in climate information services in Africa. Economic Commission for Africa. Addis Ababa, Ethiopia. https://www.uncclearn.org/wp-content/uploads/library/b11990338.pdf. Accessed Feb 13 2022

FAO (2013) Climate-smart agriculture: sourcebook. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/i3325e/i3325e.pdf. Accessed on Dec 11 2021

FAO, IFAD, UNICEF, WFP, WHO (2020) The state of food security and nutrition in the world. Transforming food systems to deliver affordable healthy diets for all. https://doi.org/10.4060/CA9692EN. Accessed Nov 16 2021

FAO, World Bank (2017) How to integrate gender issues in climate-smart agricultural projects. Training module. The Food and Agriculture Organization of the United Nations and The World Bank Rome, 2017. http://www.fao.org/3/i6097e/i6097e.pdf. Accessed Nov 16 2021

Filippini M, Greene WH, Kumar N, Martinez-Cruz AL (2018) A note on the different interpretation of the correlation parameters in the bivariate probit and the recursive bivariate probit. Econ Letters 167:104–107. https://doi.org/10.1016/j.econlet.2018.03.018

Greene WH (2018) Econometric analysis. (8th ed.), Pearson Education, United Kingdom, pp. 725–822 (8th ed.)

Guido Z, Zimmer A, Lopus S, Hannah C, Gower D, Waldman K, Krell N, Sheffield J, Caylor K, Evans T (2020) Farmer forecasts: impacts of seasonal rainfall expectations on agricultural decision-making in Sub-Saharan Africa. Clim Risk Manag 30:100247. https://doi.org/10.1016/j.crm.2020.100247

Gumucio T, Hansen J, Huyer S (2018) Identifying pathways for more gender-sensitive communication channels in climate services. CCAFS Info Note. CGIAR Research Program on Climate Change,

Agriculture and Food Security (CCAFS), Wageningen, Netherlands. https://hdl.handle.net/10568/96531

Henriksson R, Vincent K, Archer E, Jewitt G (2021) Understanding gender differences in availability, accessibility and use of climate information among smallholder farmers in Malawi. Clim and Dev 13(6):503–514. https://doi.org/10.1080/17565529.2020.1806777

Kumar U, Werners SE, Paparrizos S, Datta DK, Ludwig F (2021) Co-producing climate information services with smallholder farmers in the Lower Bengal Delta: how forecast visualization and communication support farmers' decision-making. Clim Risk Manag 33:100346. https://doi.org/10.1016/j.crm.2021.100346

Kurgat BK, Lamanna C, Kimaro A, Namoi N, Manda L, Rosenstock TS (2020) Adoption of climate-smart agriculture technologies in Tanzania. Front in Sust Food Sys 4. https://doi.org/10.3389/fsufs.2020.00055

Li C, Poskitt DS, Zhao X (2019) The bivariate probit model, maximum likelihood estimation, pseudo true parameters and partial identification. J Econom 209(1):94–113. https://doi.org/10.1016/j.jeconom.2018.07.009

Linting M, van der Kooij A (2012) Nonlinear principal components analysis with CATPCA: a tutorial. J Pers Asses 94(1):12–25. https://doi.org/10.1080/00223891.2011.627965

McHugh ML (2012) Interrater reliability: the kappa statistic. Biochemia Medica 22(3):276–282

McKune S, Poulsen L, Russo S, Devereux T, Faas S, McOmber C, Ryley T (2018) Reaching the end goal: do interventions to improve climate information services lead to greater food security? Clim Risk Manag 22:22–41. https://doi.org/10.1016/j.crm.2018.08.002

Muema E, Mburu J, Coulibaly J, Mutune J (2018) Determinants of access and utilisation of seasonal climate information services among smallholder farmers in Makueni County, Kenya. Heliyon 4 (11). https://doi.org/10.1016/j.heliyon.2018.e00889

Muita R, Dougill A, Mutemi J, Aura S, Graham R, Awolala D, Nkiaka E, Hirons L, Opijah F (2021) Understanding the role of user needs and perceptions related to sub-seasonal and seasonal forecasts on farmers' decisions in Kenya: a systematic review. Front Clim 3:10. https://doi.org/10.3389/fclim.2021.580556

Musafiri, CM, Kiboi M, Macharia J, Ng'etich OK, Kosgei DK, Mulianga B, Okoti M, Ngetich FK (2022) Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter? Heliyon 8 (1). https://doi.org/10.1016/j.heliyon.2021.e08677

Mwaniki FN, Gichuki C, Mwangi M, Mburia P, Wandago B (2017) Addressing challenges in communicating adaptation practices to smallholder farmers in Kenya through a radio intervention. J Agric Env Inter Dev 111(2):279–322. https://doi.org/10.12895/jaeid.20172.589

Ndavula JO, Lungahi EG (2018) The role of vernacular radio in climate change information dissemination in semi-arid areas in Kenya. Afr Multid J Res 3(1):110–129. https://journals.spu.ac.ke/index.php/amjr/article/view/41

Ngigi MW, Mueller U, Birner R (2017) Gender differences in climate change adaptation strategies and participation in group-based approaches: an intra-household analysis from rural Kenya□. Ecol Econ 138:99–108

Ofori SA, Cobbina SJ, Obiri S (2021) Climate change, land, water, and food security: perspectives from Sub-Saharan Africa. Fron in Sust Food Syst 5. https://www.frontiersin.org/articles/10.3389/fsufs.2021.680924

Owusu V, Ma W, Renwick A, Emuah D (2021) Does the use of climate information contribute to climate change adaptation? Evidence from Ghana. Clim and Dev 13(7):616–629. https://doi.org/10.1080/17565529.2020.1844612

Partey ST, Dakorah AD, Zougmoré RB, Ouédraogo M, Nyasimi M, Nikoi GK, Huyer S (2020) Gender and climate risk management: evidence of climate information use in Ghana. Clim Chan 158(1):61–75. https://doi.org/10.1007/s10584-018-2239-6

Phiri AT, Toure HM, Kipkogei O, Traore R, Afokpe PM, Lamore AA (2022) A review of gender inclusivity in agriculture and natural resources management under the changing climate in Sub-Saharan Africa. Cogent Soc Sci 8(1):2024674. https://doi.org/10.1080/23311886.2021.2024674

Roudier P, Sultan B, Quirion P, Baron C, Alhassane A, Traoré SB, Muller B (2012) An ex-ante evaluation of the use of seasonal climate forecasts for millet growers in SW Niger. Int J of Climat 32(5):759–771. https://doi.org/10.1002/joc.2308

Schürmann A, Kleemann J, Fürst C, Teucher M (2020) Assessing the relationship between land tenure issues and land cover changes around the Arabuko Sokoke Forest in Kenya. Land Use Policy 95:104625. https://doi.org/10.1016/j.landusepol.2020.104625

Serra R, McKune S (2016) Climate information services and behavioral change: the case of Senegal. Sahel Research Group Working Paper No. 010. https://sahelresearch.africa.ufl.edu/files/SRG_WorkingPaper_Serra_McKune_Final.pdf

Tall A, Coulibaly JY, Diop M (2018) Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: implications for Africa. Clim Services 11:1–12. https://doi.org/10.1016/j.cliser.2018.06.001

Tembo-Nhlema D, Vincent K, Malinga H (2019) Creating useful and usable weather and climate information – insights from participatory scenario planning in Malawi. Centre for Climate Change Economics and Policy Working Paper No. 357. https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2019/09/working-paper-325-Tembo-Nhlema-et-al.pdf

Tsige M, Synnevåg G, Aune J (2020) Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers. Scien Africa 7. https://doi.org/10.1016/j.sciaf.2019.e00250

UNDP (2017) Gender and climate change - overview of linkages between gender and climate change. https://reliefweb.int/report/world/gender-and-climate-change-overview-linkages-between-gender-and-climate-change. Accessed Aug 28 2022

Viera AJ, Garrett JM (2005) Understanding inter-observer agreement: the kappa statistic. Fam Med Res Ser 37(5):360–363

WMO (2021) State of the climate in Africa 2020. WMO-No. 1275. World Meteorological Organization. Geneva, Switzerland. https://library.wmo.int/doc_num.php?explnum_id=10854. accessed Dec 17 2021

Wooldridge JM (2010) Econometric analysis of cross section and panel data, 2nd edn. MIT Press, Cambridge, MassachusettsLondon, England

World Bank Group (2016) Climate information services providers in Kenya. Agriculture global practice technical assistance paper. No. 103186-KE. World Bank, Washington, DC. World Bank, Washington, DC. https://doi.org/10.1596/23768

Yohannis M, Wausi A, Waema T, Hutchinson M (2019) The role of ICT tools in the access of climate information in rural communities. J Sust Env Peace 1(2):32–38. https://doi.org/10.23919/ISTAFRICA.2019.8764875