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Climate hazard adaptation in Uganda's tropical highlands: an actor-network theory perspective on gendered smallholder strategies and the role of non-state actors

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ABSTRACT

Climate hazards continue to worsen smallholders' livelihoods, demanding synergy and multi-level climate adaptation strategies. While non-state actors (NSAs) increasingly support local adaptation, limited understanding exists of how gender shapes farmers' perceptions and engagement with these actors, especially in Uganda's highland farming communities. By applying the actor-network theory, we explored the gendered adaptation among smallholder farmers. We used a cross-sectional survey of 147 household interviews, two focus group discussions, and seven key informant interviews to collect data. Quantitative data were analyzed with descriptive statistics, Chi-square, and one-sample t-tests; qualitative data via content analysis. Men and women engage differently in adaptation: men focus more on tree planting and livestock, while women lead in crop production and marketing. Women also prefer resilient, indigenous crop varieties that are easier to manage and pest-resistant. Compared to men, women rely more on savings groups and informal networks to build social and financial capital. NSAs strengthen local adaptation through advisory services, soft loans, grants, agricultural diversification, and conservation practices. Actor-Network Theory offers a valuable lens for understanding gendered climate adaptation by highlighting the synergies between actors within structured networks. Aligning interventions with gender-specific strengths is essential for fostering inclusive, climate-resilient livelihoods and advancing global climate goals.

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Climate Change; Agriculture; Agriculture & Environmental Sciences; Hazards & Disasters; Physical Geography; Human Geography

1. Introduction

Climate change increasingly poses significant socioeconomic, environmental, health, and political challenges to farmers globally, especially in the 21st century (Paudyal et al, 2019). Its impacts are evident through the increased frequency and intensity of hazard events such as erratic rainfall, droughts, and floods (Ackerl et al., 2023; Isunju et al., 2016; Nalwanga et al., 2024). These changes threaten the livelihoods of smallholder farmers who include small-scale crop producers, pastoralists, forest users, and fisherfolk managing farms typically smaller than ten hectares (FAO, 2016). Their farming systems are often family-centered, relying heavily on household labor and partially oriented toward subsistence.

Smallholders play a crucial role in food systems, particularly in low- and middle-income countries. In Africa, they account for the majority of agricultural production, utilizing about 80% of the farms (Akanmu et al., 2023). Despite their contributions, they remain highly vulnerable to climate shocks. Studies estimate that farms under five hectares produce a significant portion of global food, yet smallholders often lack access to the resources needed to adapt to a changing climate (Restrepo et al., 2023; Twongyirwe et al., 2019). In highlands areas, Climate-related hazards disrupt agricultural systems through increasing landslides, floods, and increased pest and disease outbreaks that affect crop production (Kisira et al., 2023; Mutyebere et al., 2024). These effects have led to food insecurity, biodiversity loss, and weakened rural livelihoods.

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The Least Developed Countries (LDCs), particularly in Africa, bear the brunt of these changes despite contributing the least to global greenhouse gas emissions. Uganda is no exception, climate change and related hazards continue to undermine progress toward national goals such as Vision 2040, the Sustainable Development Goals (SDGs), and the National Development Plan IV, which identifies agriculture as a key driver of development (Okello et al., 2018; M. Okello et al., 2020). While some research has focused on the general impacts of climate change on smallholder agriculture (Balikoowa et al., 2019; Danso-Abbeam et al., 2021; Fadina & Barjolle, 2018; Filho et al., 2019; IPCC, 2023). There is still a knowledge gap in understanding how NSAs promote priorities of men and women smallholder farmers to implement adaptation strategies at household and farm levels, especially in African contexts where roles are gender constructed. Moreover, the role of non-state actors (NSAs) in promoting gender-sensitive adaptation, especially during climate stress events like prolonged dry spells, also remains underexplored.

It is essential to understand how gender roles influence household and on-farm roles amidst climate change hazards for effective adaptation responses (Nalwanga et al., 2025). In African rural contexts, men and women adopt different strategies; men often favor market-oriented responses such as mechanization and drought-resistant cash crops, while women prioritize food security through practices like crop diversification, backyard gardens, and soil conservation (Vallury et al., 2024). These preferences shape how NSAs and other actors should design and implement interventions. Crucially, connecting NSA-driven gendered practices to broader outcomes such as biodiversity conservation, food system resilience, and equitable access to climate finance remains an urgent research frontier (IPCC, 2023; National Planning Authority (NPA),), 2024). Our study therefore aims at providing operational information vital for integrating gender-responsive adaptation strategies into national and global frameworks for climate resilience.

1.2. Non-State Actors in Climate Adaptation

Non-state actors (NSAs), including civil society organizations, business associations, local authorities, and research groups, play a pivotal role in climate adaptation,governance and mitigation (Bäckstrand et al., 2017; Kuyper et al., 2017). These actors innovate policies and strategies to strengthen resilience, and support national efforts to bridge the emission gap (Bettles et al., 2021). NSAs mobilize resources, influence behaviors, and bolster governments' confidence and political will to advance climate ambitions, making them integral to the implementation of the Paris Agreement (Jernnäs & Lövbrand, 2022; Maclean, 2020). Examples of NSA engagement include the Collines region's inter-village assembly in Benin, where Non-Government Organizations (NGOs) and local authorities collaborate to tackle climate challenges (Dapilah et al., 2021), and Morocco's '4C Maroc' project, which unites public and private entities to address climate change (Jaouhari et al., 2021). NSAs also advocate sustainable agricultural practices, file environmental lawsuits, and demand increased climate financing from developed nations (Asselt, 2016; CORDAID, 2016). In Africa, platforms such as the African Non-State Climate Action (ANSCA) initiative amplify NSA visibility and foster collaboration to meet the Paris Agreement targets (Hale, 2018).

Beyond advocacy, NSAs continue to carry the agenda of the Paris Agreement by promoting access to climate mitigation practices such as tree planting, wetland conservation, and soil fertility enhancement (Kuyper et al., 2018). They engage smallholder farmers by linking them with scientists and decision-makers, disseminating localized climate advisories, and promoting indigenous knowledge in agricultural and natural resource conservation (Bimir, 2022). NSAs significantly enhance climate governance by facilitating policy development, business models, and capacity-building efforts to reduce emissions and build resilience (Hale, 2018). They act as knowledge co-producers, brokers, and policy advocates, connecting diverse stakeholders to foster inclusive and effective climate actions (Bäckstrand et al., 2021; Nasiritousi et al., 2016). However, there there is a need to use a gender lens and actor-network theory to also understand these contributions that are critical for achieving national climate goals and reducing vulnerability to climate hazards among agricultural communities.

1.3. Contextual rationale

In Uganda, NSAs play a significant role in climate change adaptation among smallholder farmers in rural communities. However, their contributions remain poorly documented despite the country's heavy

reliance. Approximately 70–97% of Ugandan households engage in small-scale and rainfed agriculture, making them highly vulnerable to climate change impacts (FAO, 2024). Of these, smallholder farmers comprise 85% of Uganda's farming community. In Kigezi highlands, households depend on small-scale crop growing and animal rearing as the major source of food on less than 2 hectares through rudimentary methods. These farmers mainly grow food crops including maize, Irish potatoes, beans, and bananas. Animals like cattle, goats, pigs poultry among others are kept by some farmers. Smallholder farmers grow crops majorly for food and the surplus is sold off for revenue to access basic needs including household education, health, clothing, income, and shelter (UBOS, 2016). Amidst climate-related hazards that affect their agricultural activities, 37.5% of the population earns less than $1.25 one hectare per season daily, and limited access to resources exacerbates their vulnerability to food insecurity and chronic poverty (Atube et al., 2021; Mubiru et al., 2018). Reliance on rain-fed agriculture worsens their vulnerability to to erratic weather patterns, including unpredictable rainfall, prolonged droughts, and floods, through disrupting planting and harvesting schedules consequently affecting crop yields. Rising temperatures and shifting precipitation patterns in the area strain their crop and livestock production (Dapilah et al., 2021). Smallholder farmers are further constrained by limited capacity, capital to access irrigation, resilient practices, and technologies to mitigate these challenges (Abegunde et al., 2019; Mfitumukiza et al., 2024). The deepening vulnerability to climate hazards necessitates urgent interventions to enhance income, access to food, and basic needs thus building their resilience to climate change.

NSAs contribute significantly towards climate adaptation through ecosystem conservation, and livelihood improvement. However, empirical evidence of gendered contributions to climate adaptation in disaster-prone areas of Uganda is limited. Understanding evidence-based differentiated vulnerabilities, decision-making patterns, labor burdens, and access to adaptation resources between male and female farmers enables policymakers and NSAs to tailor programs that acknowledge and address these disparities. In addition, the study leverages the Actor-network principles to document scalable gendered models of participatory climate action. NGOs, civil society, and farmer organizations are critical partners in implementing national climate change frameworks, such as Uganda's National Climate Change Policy (2015), and the five-year National Adaptation Plans. Gender-inclusive policies such as targeted credit schemes and women-led extension programs through the NSA including faith-based, agencies, and groups enhance adaptive capacity across women and men. We examine the role of NSAs in supporting smallholder farmers' adaptation to climate change, focusing on the Kigezi region, a hotspot for climate extremes. By exploring household and on-farm adaptation dynamics, this study provides a discussion on how NSAs can effectively promote adaptation to climate hazards and disasters among smallholder farmers in Uganda. Results can be used to strengthen gender mainstreaming in international climate financing mechanisms, such as the Green Climate Fund (GCF). The following research questions guided our study:

RQ1: What are the household and on-farm gendered adaptation dynamics to climate hazards among smallholder farmers?

RQ2: How are Non-State Actors (NSA) promoting gendered adaptation to climate hazards among smallholder farmers?

2. The actor-network theory (ANT)

We applied the Actor-Network Theory (ANT), a framework developed in the mid-1980s by Bruno Latour, Michel Callon, and John Law to discuss the role of non-state actors in climate adaptation. ANT was particularly useful for examining the complexities of climate adaptation strategies and the pivotal roles of actors including non-state actors. It emphasizes the interplay (i.e. as depicted by the red cyclic arrows in Figure 1), between human and nonhuman actors including technologies, institutions, and objects, in shaping social phenomena and adaptation efforts. In the context of smallholder agriculture and climate change adaptation, ANT conceptualizes adaptation as networks and relationships formed among diverse stakeholders such as local communities, indigenous groups, and non-governmental organizations (NGOs).

These networks interact to shape the community's resilience and adaptation outcomes. This approach is particularly relevant for understanding how various actors such as farmers, extension services, and technology providers collaborate to promote adaptation strategies highlighting the dynamics of social learning and collective action (see seen in Figure 1). It also challenges traditional sociological perspectives by recognizing the influence of non-human entities within the network. With this, we did not only look at the existence of the actors but also their roles. This supported the study to demystify how diverse actors such as farmers, faith, humanitarian, education, and financial bodies interact, and collaborate to design and implement effective gendered adaptation strategies for smallholder farmers in Uganda's rural areas such as the tropical mountains.

In addition, the Actor-network theory (ANT) offered a suitable procedure for debating the interwoven relationships and actor dynamics central to gendered climate adaptation. ANT's core premise that both human and non-human actors (e.g. weather systems, extension services, financial platforms) collaboratively shape outcomes directly informs the investigation of gendered adaptation dynamics (RQ1) and the role of non-state actors (RQ2). ANT's focus on the complexity of reality and its inclusion of both human and nonhuman actors also provided a theoretically informed approach to sampling and analysis (Deason et al., 2022).

We also further used ANT to guide gender sensitivity by treating women and men not as homogenous categories, but as differentiated actors embedded within distinct yet overlapping networks of support, constraint, and agency (see Figure 1). To operationalize ANT in the research process, we identified key female and male actors from farmers, NSAs, agricultural inputs, technologies, and social institutions. We then traced their roles and assessed how these influence household-level and on-farm adaptation choices by women and men farmers. In addition, for RQ1, ANT enabled the exploration of how gendered actors (men and women farmers) are embedded in diverse networks that determine their adaptive strategies, resources, and constraints. For RQ2, ANT provided a framework for analyzing how NSAs such as faith-based groups, NGOs, and development agencies mediate knowledge, finance, and technical inputs through their interactions with households and other actors in the network. We fully utilized the principles of the theory in grounding the data collection procedure (e.g. identification of key informants, and

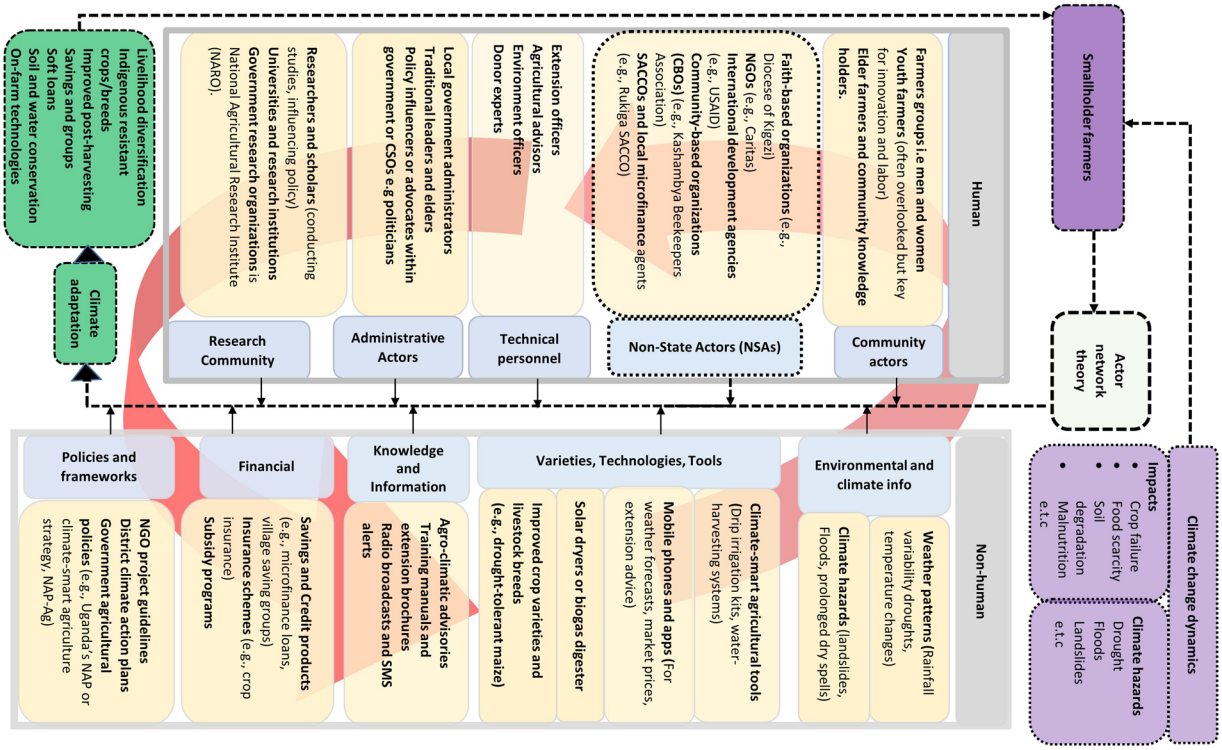

Figure 1. The conceptualization of the actor-network theory and contextualization of the role of non-state actors in climate adaptation. The dotted black lines are the paths depicting how the current study debates the role of non-state actors toward smallholder farmers' adaptation to climate hazards.

focus group participants). It also guided the analytical focus of mapping actor influence, and shaped interpretation by revealing how adaptation emerges from a web of networks rather than isolated decisions.

3. Materials and methods

The study was conducted in Kashambya sub-county, which lies in the northern part of the Rukiga district of southwestern Uganda (see Figure 2). The Rukiga district covers an area of 426 square kilometers (UBOS, 2014). It is bordered by the Ntungamo District to the east, the Republic of Rwanda to the southeast, Kabale District to the southwest, Rubanda District to the northwest, and Rukungiri District to the north. The district has other subcounties such as Bukinda, Kamwezi, and Rwamucucu as shown in Figure 2. The area experiences a warm to cool humid climate with a bimodal rainfall pattern, receiving an average annual rainfall of approximately 1,092 mm. In higher elevation zones exceeding 2,000 meters above sea level, rainfall amounts rise significantly, ranging between 1,250 mm and > 1,540 mm.

The 2024 census report places Rukiga district as one of the most densely populated districts in the Kigezi region with a total of 132,029, with 64,083 males and 67,946 females. With a density of 310 persons per square kilometer, its density surpasses the country's average density of 227 persons per square kilometer. It has 33,810 total households with an average household size of 3.9 (UBOS, 2024). The district recorded a population growth rate of 2.8% between 2014 to 2024. Being a rural area, the majority > 71.3% of inhabitants engage in smallholder agriculture on heavily fragmented land parcels. Located in a highland region, farmers grapple with steep terrain that stimulates climate-related hazards such as soil erosion and landslides during rainy season. The increasing occurrence urgently requires implementing resilient and adaptive farming practices. The majority of the smallholder farmers grow food crops which include sorghum, Banana, Sweet potato, Irish, and beans. Animals kept include cross breeds and Indigenous cattle, goats, pigs, and rabbits (Kabale District Council (KDC)), 2016).

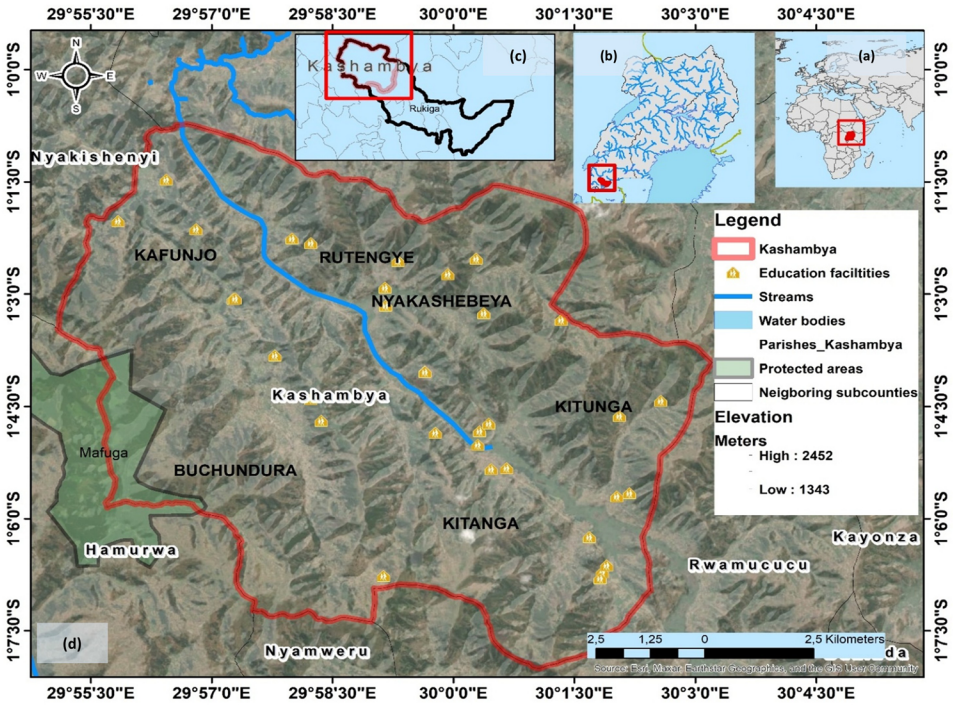

Figure 2. Location of the study area. Figure 2 (a) Uganda, (b) Rukiga district in Uganda, and (c) Kashambya sub-county. In 2 (d), is Kashambya subcounty in a bigger view with its parishes and terrain.

3.2. Climate hazards, farmers, and NSAs

Rukiga district, situated in the Kigezi highlands, presents a compelling case for this study due to its heightened vulnerability due to climate hazards and terrain factors. The area frequently experiences intense rainfall, which accelerates soil erosion and land degradation. This is further compounded by the continuous deposition of sediments into wetlands, largely originating from exposed hillside farming plots (Sahani, 2024). Although farmers rely on traditional bench terraces to manage the heavy overland flow on steep slopes, these structures are often outdated and ineffective, resulting in substantial soil loss (Nadhomi et al., 2022). Additionally, the district has seen a rising incidence of landslides (see Figure 3a), posing serious threats to both livelihoods and ecological stability as depicted in Figures 3b and 3c (Kisira, 2019; Nseka et al., 2021).

Given the area's proneness of climate-related hazards and consequences, the involvement of non-state actors (NSAs) became particularly significant (Sahani, 2024) see Table 1. Operating outside the formal state structures, NSAs such as NGOs, CBOs, faith-based groups, and private institutions have increasingly taken on various roles including financial and advisory roles in supporting climate adaptation and sustainable land management in the region. Their presence and interventions, including those of Nature-Uganda, Caritas, USAID, and local cooperatives like Rukiga SACCO, provide a unique opportunity to investigate how such actors shape and influence gendered household and farm-level coping strategies.

3.1. Research design

We adopted a cross-sectional research design to have a deeper analysis combining quantitative and qualitative methods and gather adequate information from various units in the Kashambya sub-county. We collected data considering various factors such as respondent's gender, age, location, and experience farming. Qualitative data formed the foundation for analyzing farmers' perspectives and stories. In

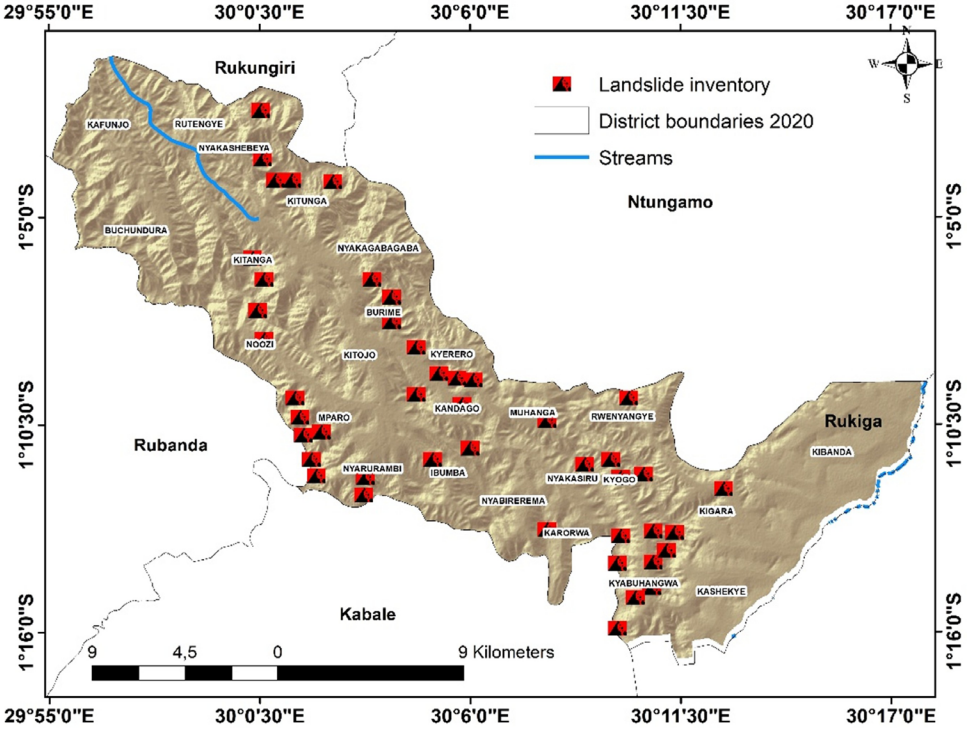

Figure 3a. Field landslide inventory in the study area. These landslide hazards degrade soil quality, destroy terraces, and damage crops see Figure 3 (b) & 3 (c).

Figure 3b. Banana plantation swept away by a landslide in Rukiga. Smallholders' perennial food source and livelihood buried under mud (Source of the photo: Nseka et al., 2021). Figure 3c: A hillslope in the Kigezi Highlands showing severely degraded bench terraces caused by climate-induced runoff and soil erosion on fragmented smallholder land parcels, leading to reduced crop yields (Source of the photo: Nadhomi et al., 2022).

quantitative methods, emphasis was placed on collecting measurable facts regarding the distribution of lived experiences toward climate hazard adaptation.

Between 2022 and 2023, when the survey was conducted, we used the population projection for 2021 to determine the sample (Uganda Bureau of Statistics (UBOS), 2020). The projection estimated that Rukiga District had a total of 23,136 households by 2021. Of these, 5,929 were in Rwamucucu, 2,225 in Bukinda, 2,766 in Muhanga Town Council, 6,287 in Kamwezi, and 5,929 in Kashambya Sub-county. The 5,929 households in Kashambya Sub-county constituted the target population. Yamane's (1970) formula was used to determine the sample size for face-to-face interviews.

$$\text{Yamane's formula is expressed as: } n = \frac{N}{1+N(e^2)}. \quad \text{(i)}$$

Where n is the sample size, N is the population size, and e is the error or precision margin. Therefore, given N (smallholder farmer Households in Kashambya sub-county) =5929, e^2=0.0049, the sample size n obtained was 197, containing both men and women.

This sub-county is composed of six parishes: Bucundura, Kafunjo, Rutengye, Kitanga, Kitunga, and Nyakashebeya. These six parishes formed the sampling framework from which the sample was drawn. Household heads in these parishes were randomly interviewed through face to face using semi-structured questionnaires, comprising both open-ended and closed-ended questions. The face-to-face interviews facilitated a deeper and physical discussion of climate change adaptation dynamics, reducing the likelihood of misinterpretations. During the process, we requested privacy from the spouses of respondents to mitigate the failure of free expression especially among female respondents (Nalwanga et al., 2025). We also purposively sampled key informants with recommendable knowledge of climate adaptation and NSA actors. We therefore sampled seven key informants i.e. the District Production Officer (DPO), District Community Development Officer (DCDO), District Environment Officers (DEO), and four sub-county Agricultural Extension Officers (AEO). Also, two focus groups with 8 participants each were conducted in Kashambya sub-county. To encourage open discussion of their social experiences and minimize the influence of cultural biases due to power imbalances in the patriarchal African society, women and men were organized into separate groups. These groups included youths, farmers, and elders, ensuring a broad range of perspectives and diverse representation across gender and age categories as recommended by scholars in gender and climate adaptation (Nalwanga et al., 2025).

Table 1. Categorization of the actors.

Categories of NSAs	Description of climate adaptation roles
1: Sustainable agriculture and environmental conservation	
Nature-Uganda	Promotes savings and loan schemes, wetland and hill slope conservation, and the adoption of sustainable agricultural practices.
Emmaus International	Implements agroforestry, diversified farming systems, supports savings groups, and encourages clean energy use among smallholder farmers.
International Crane Foundation (ICF)	Focuses on wetland conservation, sustainable wetland utilization, and delivery of agriculture-related extension services.
Margaret Pyke Trust (MPT)	The project has supported community members by distributing Napier grass, training them in trench and terrace construction, and promoting its planting on hills around wetlands to reduce soil erosion and prevent sediment contamination of wetland water.
Red Cross	Facilitates integrated organic farming, promotes agroforestry, and provides support for disaster preparedness and response.
Kashambya Beekeepers Association	Mobilizes beekeepers, supports organic farming and environmental conservation, promotes value addition, and conducts market research.
2: Agricultural extension and capacity building	
USAID	Works to reduce poverty and hunger, strengthen agricultural systems, and improve community health outcomes.
Compassion International	Supports child nutrition, poverty alleviation, education, and financial assistance to children affected by HIV/AIDS.
Caritas	Offers agricultural extension services, provides financial support, and encourages community savings initiatives.
Kigezi Potato Crescent	Supplies improved planting materials, promotes proper storage of Irish potatoes, and engages in agricultural market research.
Diocese of Kigezi Fathers' Family	Social and spiritual support, community sensitization on improved farming practices, value addition, and conservation-oriented agriculture.
AVIS	Enhances farmer education, promotes diversified agriculture, strengthens livelihoods, and offers extension services.
3: Financial services for adaptation	
Kashambya Multipurpose Union	Provides credit facilities, promotes joint marketing, and enforces mandatory savings for climate-resilient farming enterprises.
Rukiga SACCO	Extends financial credit to farmers, facilitates procurement of agricultural inputs, supports value addition, and mobilizes savings.

Source: District Community Development Office, (2024) and Internet resources.

The data collection tools were validated through expert and peer review, including input from the research team, and community technical people such as senior agricultural officials and extension workers. Before the full-scale data collection, a four-day pilot study was conducted using face-to-face interviews with ten selected smallholder farmers who voluntarily participated in the pretesting exercise. To minimize respondent bias, a separate group of ten other farmers from a different village was randomly selected and subjected to the piloted questionnaires and interviews. The results from both rounds were nearly identical, indicating consistency, and the tools were thus approved for use in the main study. Feedback from respondents was used to contextualize and localize the instruments, ensuring they reflected farmers' views and helped collect relevant information. This process significantly enhanced the reliability and validity of the tools. The pilot study led to improvements in both the questionnaires and interview guides by removing redundant questions, clarifying ambiguous items, and aligning conceptual with operational concepts. Furthermore, we again reviewed the pretested tools for clarity and consistency in wording, making them easier to administer. A statistical test for data reliability was run using Cronbach's alpha. A value of 0.88 above the threshold of 0.7 was returned indicating a high level of internal consistency. We then proceeded with the detailed statistical analysis following the research questions.

3.2. Data analysis

Content analysis was used to analyze the data obtained from the key informant interviews to extract relevant information based on the study. We recorded the discussions and transcribed them. We then listened systematically to the stories given by the farmers to manually generate quotes and narratives that explained the raised questions accurately (Hsieh & Shannon, 2005). After cleaning, entering, and processing the questionnaires, a total of 147 (74.62%) questionnaire forms were complete and with consistent responses. These were considered for statistical analysis using the chi-square and one sample t-test in the Statistical Package for Social Sciences (SPSS) version 23. Pearson's chi-square test was used to ascertain the association of adaptation strategies with men and women. The Chi-square test is a widely used nonparametric test that involves a comparison between what is observed and what would be expected by chance. Pearson's Chi-square test can be denoted as;-

$$x^2 = \Sigma \frac{(0_{ij} - E_i j)^2}{\Sigma_{ij}} \tag{ii}$$

where:

O_{ij} the observed frequency in each category in the i and j, column of the contigency table

E_{ij} the expected frequency in the i row and J column as calculated as,

$$E_{ij} = \frac{\left(row\ \ total_i\ x\, column\ \ total_j\right)}{grand\ \ total} \tag{iii}$$

This test checks whether there is a significant association between two categorical variables. The larger the difference between observed and expected frequencies, the larger the X^2 value, and the more likely it is that the variables are associated.

Also, a one-sample t-test revealed the perceived effectiveness of roles played by non-state actors towards climate adaptation across women and men. The algorithm for a one-sample t-test model can be denoted as;

$$t = \frac{\times - \mu}{S / \sqrt{n}} \tag{iv}$$

Where,

μ, Population mean,

$\times$, Sample mean,

S, Sample standard deviation,

n, Sample size,

t, The t value (number of sample standard deviation (S), the sample mean ($\times$) is away from the population mean (μ).

3.3. Informed consent and Declaration of Helsinki statement

All participants in this study provided full, informed consent before their involvement in the interviews, affirming their voluntary participation. Written consent forms were filled out by all the groups including focus group discussion participants. For the face-to-face household interviews, informed consent was incorporated within the questionnaire tool and explicitly explained by the researcher during data collection. We adhered to the principles of the Declaration of Helsinki that apply to a social research survey. The consent form explained details of the study including purpose, potential risks, and anticipated benefits. For those who consented, the study's objectives and any potential risks such as interview fatigue or psychological distress were communicated before the interview process commenced. We could allow health breaks during the interviews, especially with female participants who would request some time to attend to household chores during the interaction. Participants had a right to withdraw from the

study or decline to answer any question at any stage, without any consequences. Participants also consented and agreed to the use of their responses in academic publications, including manuscripts, with strict adherence to confidentiality and accuracy.

4. Results

The sociodemographic categories of the respondents are presented in Appendix 1. Fifty percent of the respondents were male and 50% were female. The majority (75%) were above 35 years old and the rest were younger. Eighty-three percent were married, 5% were single, 11% were widowed, and 2% were divorced. In terms of education, 54% had secondary education, 5% had vocational training, and 15% were university graduates. Ten percent had primary education, while 16% never attended school. A majority (81%) of the respondents owned less than five acres of land, while 16.3% owned less than one acre. Nineteen percent owned more than five acres, 16% had 6–10 acres and 4% owned more than 11 acres of land.

4.1. Dynamics of gendered adaptation to climate hazards

To establish a clear and precise story on farmers' insights into climate change dynamics, we delved into asking their opinions on how climate change has affected female and male farmers. We asked farmers how female and male farmers effectively participated in climate change adaptation at the household level and later on the farm. We found out that female farmers were perceived to be the most affected by climate change effects (reported by 75% of the respondents), partly because they were mostly involved in agriculture and food production (Figure 4). Women were also perceived to have limited capabilities to cope with the effects of climate change. This limitation was due to unfavorable power relations that curtailed women's ownership of land and limited employment opportunities.

4.1.1. Household-Based strategies for climate hazard adaptation

The Chi-square analysis revealed significant independence in the effectiveness of household activities undertaken by women and men in adapting to climate change at the household level (Table 2). The majority of respondents (95%) identified women as the most effective crop growers (χ^2 = 116.7, n = 147,

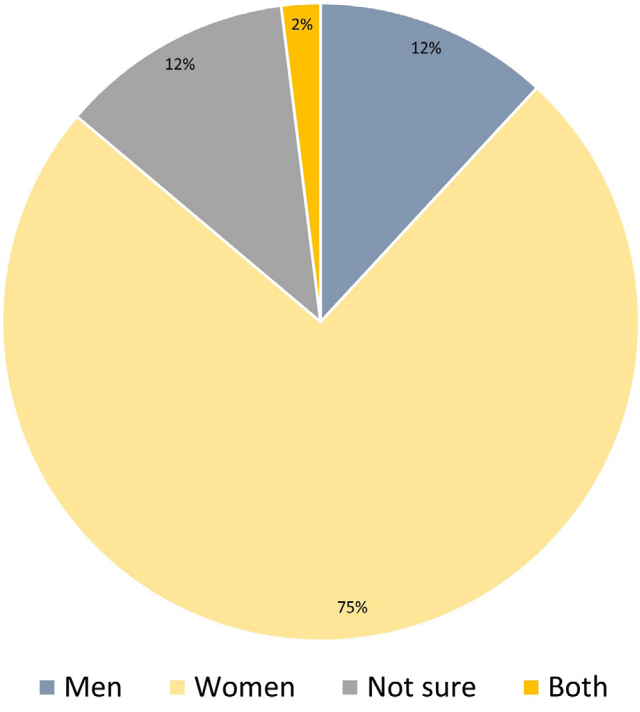

Figure 4. Climate change effects across gender (n = 147).

df = 1, $p < 0.001$), highlighting their reliance on crop production, which is particularly vulnerable to climate shocks such as early rainfall cessation. A female key informant attributed women's heightened vulnerability to existing social and economic inequalities, including limited land ownership rights, restricted access to weather-related technologies, unequal power dynamics affecting credit access, and lower education levels.

Additionally, women were perceived as more effective in marketing agricultural produce, as reported by 75% of respondents (χ^2 = 36.2, n = 147, df = 1, $p < 0.001$). This was affirmed during a focus group discussion in the Kafunjo parish, where a participant stated that:

> …things are changing, men no longer control households… me and my children, when it comes to selling our produce. Instead of surrendering the money to him to go and drink, we would rather be beaten with the money in our pockets…

This was linked to the minimal involvement of men in food crop farming, with some men reportedly unaware of the crops that women cultivated. In contrast, livestock management and agroforestry were predominantly undertaken by men, as reported by 82% and 88% of respondents, respectively. These activities were significantly associated with male involvement (livestock management: χ^2 = 58.8, n = 147, df = 1, $p < 0.001$; agroforestry: χ^2 = 83.8, n = 147, df = 1, $p < 0.001$). Traditionally, men have been responsible for rearing animals, such as sheep, cows, and goats, while women and children focus on managing smaller livestock, such as pigs, poultry, and rabbits. Men's involvement in agroforestry and cash crop production is often tied to the perennial nature of these activities, aligning with their decision-making roles in farming households.

4.1.2. Gendered on-farm adaptation strategies and their effectiveness

The effectiveness of adaptation strategies was assessed using a Likert scale ranging from 1 to 5, where 1 indicated 'very effective', 2 'effective', 3 'not sure', 4 'ineffective', and 5 'very ineffective'. The t-test results revealed that the majority of farmers perceived all adaptation strategies as effective (M = 2), helping mitigate climate change shocks and threats among smallholder farmers (Table 3). Planting resilient crop varieties and cultivars emerged as the most effective strategy for adapting to the adverse effects of climate change (M = 2, SD = 1.054, t = 5.1, $p < 0.001$), with 37% of female farmers endorsing this approach compared to 34% of male. Indigenous varieties of beans, maize, and Irish potatoes were commonly planted because of their resilience to climate shocks, whereas promoted cultivars included apples, Hass avocados, and bananas. Conservation agriculture ranked second among the effective practices promoted by non-state actors to help farmers cope with prolonged dry spells, soil moisture loss, and severe runoff during heavy rain. This strategy was supported by t-test results (M = 2, SD = 1.014, t = 5.3, $p < 0.001$). Male respondents (35%) favored conservation agriculture slightly more than females (32%). Key practices included planting cover crops, mulching with crop residues (Figure 5), crop rotation, and constructing contour bunds to control the surface runoff.

Farmers also practiced agricultural diversification reported by 33% of the males and 33% of the females (Table 3). This strategy was effective in reducing climate change risks among smallholder farmers ($M = 2$, $SD = 0.97$, $t = 5.8$, $p < 0.001$). Mixed farming involves crop farming and the rearing of poultry and pigs. In most cases, the land is divided into plots to accommodate food and cash crops, vegetables, legumes, orchards, and grains (maize and beans). Farmers reported that mixed cropping (see Figure 5) enhanced their livelihood sources and reduced their over-dependence on crops that were highly susceptible to drought, runoff, early rainfall cessation, and other climate change shocks.

Table 2. Adaptation activities at the household level across female and male farmers (n = 147).

	Responses (%)		Pearson's chi-square	
Activities	Men	Women	χ^2	*p*-value
Livestock management	82	18	58.837	0.000
Crop production and management	5	95	116.741	0.000
Agro-forestry practices	88	12	83.816	0.000
Marketing of agricultural produce	25	75	36.252	0.000

χ^2= chi-value, the larger the χ^2 value, the more likely it is that the variables are associated. *p*value - whether that association is statistically significant based on the size of the Chi-value and the difference in the frequency. In this table, results depicted large variations in the frequencies across men and women towards implementing different strategies.

Table 3. T-Test results comparing the perceived effectiveness of on-farm activities between female and male farmers (n = 147).

	Number of farmers (%)		One sample t-test Test value =1 (very effective)					Descriptive			
Adaptation strategies	F	M	t	df	Sig. (2-tailed)	Mean	SEM	Mode	Std. Dev	Var	Total score
Productive crop varieties and cultivars	37	34	5.08	146	0.00	2	0.08	2	1.05	1.11	359
Productive livestock breeds	33	27	8.08	146	0.00	3	0.08	2	.99	.979	391
Conservation agriculture	32	35	5.28	146	0.00	2	0.08	2	1.01	1.02	359
Agricultural diversification	33	33	5.84	146	0.00	2	0.08	2	.974	.949	363
Small scale irrigation	25	21	10.6	145	0.00	3	0.08	2	1.06	1.13	429
Improved post-harvest handling and storage	30	26	8.05	145	0.00	3	0.09	2	1.13	1.27	402

Note: Var-Varience; SEM = standard Error mean, df = degree of freedom, F = female, M = Male, t = T-test value i.e (statistical difference between sample and population mean; Var-Varience; SEM = standard Error mean, df = degree of freedom, F = female, t = T-test value i.e (statistical difference between sample and population mean. The size of the t-value in a positive direction shows the strength of the agreement with the perceived effectiveness.

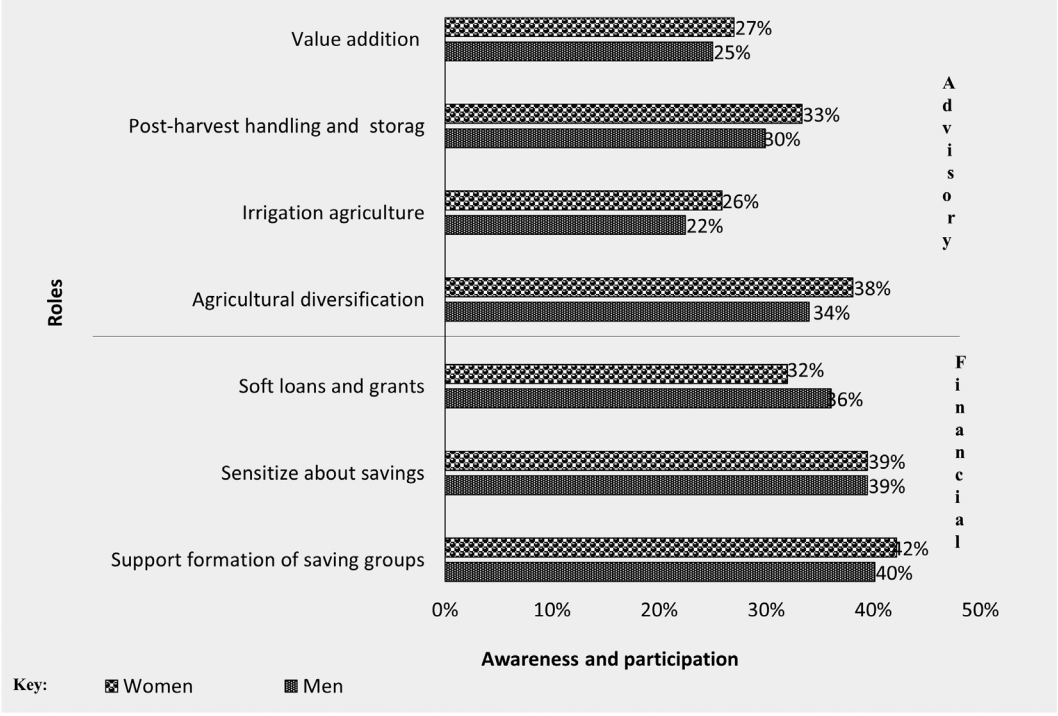

Figure 5. Roles played by non-state actors (n = 147).

4.2. The role and effectiveness of non-state actors

The roles played by non-state actors in promoting climate change adaptation among smallholder farmers are presented in Figure 4 based on gender perceptions. The findings reveal that non-state actors play significant financial and advisory roles in promoting climate change adaptation among smallholder farmers.

4.2.1. Financial roles

(a) Promoting farmer savings groups

The financial roles played by non-state actors were appreciated by smallholder farmers, especially the sensitization of farmers to form savings groups (Figure 5). Rukiga SACCO, CARITAS, Nature Uganda,

ACFODE, and World Vision International played this role. Results revealed that the role played by the NSA enabled the majority (78%) of farmers to access services such as savings and credit facilities to farmers ($M=2$, $SD=1.1$, $t=13$, $p<0.001$) (Table 4). This role promoted the habit of savings among farmers, as attested by 40% of the male respondents and 42% of the female. The need for savings enhanced the formation of saving groups among farmers, as stated by 39% of females and 39% of males. Based on the one-sample t-test results in Table 4, supporting group formation was perceived as the second role of NSAs ($M=2$, $SD=0.8$, $t=17$, $p<0.001$) in promoting climate change adaptation. The savings gave smallholder farmers some capital to invest in farming to guard against climate change shocks of prolonged dry spells and droughts that consequently cause famine. Savings improved their farming equipment by buying planting materials, paying for hired labor, and buying agro-inputs. A key informant revealed the following.

> … at least four saving groups to which I am a member were started with the support of Non-State Actors. These included the Kashambya Bee Keepers Association and the Kashambya Multipurpose Union…

He added that; -

> … Each group member was encouraged to save UGX 5,000 (Est. 1.5 USD) weekly or UGX 1,000 (Est. 0.27 USD) after every two weeks. The funds are borrowed by group members on a revolving basis at a subsidized interest rate of 2%. Member's savings are used as collateral. Women were the highest beneficiaries given the power relations that denied them ownership of land to offer as collateral …

(b) Soft credit to farmers' groups

Thirty-six percent of males and 32% of the females accessed soft loans through their groups (Figure 6). The t-test results revealed that support for farmers with soft loans was perceived as third among smallholder farmers in promoting climate change resilience ($M=2$, $SD = 1.1$, $t=13.3$, $p<0.001$).

Loans were mostly acquired from SACCOS and farmers' savings groups on affordable terms and conditions. For instance, Rukiga SACCO offered agricultural loans at only a 2% interest rate with a possible grace period of three months, loan insurance, and loan payment rescheduling provisions in situations where the farmer found it difficult to meet the payment schedules due to climate change shocks. The loans depended on the farmer's project of interest, saving culture, repayment history of the prior loans,

Table 4. Results of the t-test on how women and men perceived the effectiveness of the promoted adaptation strategies.

One sample t-test (test value = 1 for strongly agree) (n = 147)									
					95% confidence interval of the difference		Descriptive statistics		
Roles	t	df	Sig. (2-tailed)	Mean difference	Lower	Upper	Mean	SD	Std. Error mean
Sensitize farmers about savings	12.8	146	0.000	1.1	0.9	1.3	2.1	1.1	0.1
Support in the formation of saving groups	16.5	146	0.000	1.2	1	1.3	2.2	0.8	0.1
NSA extends soft loans and grants	13.3	146	0.000	1.2	1.1	1.4	2.2	1.1	0.1
Conservation agriculture	17.2	146	0.000	1.4	1.3	1.6	2.4	1	0.1
Agricultural diversification	16.6	146	0.000	1.3	1.2	1.5	2.3	1	0.1
Irrigated agriculture	21.5	146	0.000	1.8	1.7	2	2.8	1	0.1
Promotion of improved post-harvest handling and storage	17.1	146	0.000	1.6	1.4	1.7	2.6	1.1	0.1
Value addition is encouraged by the NSA	20.4	146	0.000	1.8	1.6	2	2.8	1.1	0.1

Note: Var-Varience; SEM = standard Error mean, df = degree of freedom, F = female, t = t-test value i.e (statistical difference between sample and population means. The size of the t-value in a positive direction shows the strength of the respondents' agreement with effectiveness.

and technical decision of the loan committee. On the other hand, farmers' savings associations were preferred due to their flexibility, and high sense of community ownership and management. Concerning the amount of loans taken, the key informant narrated the following:

> …most farmers came for loans recently during the COVID-19 farming season compared to previous seasons to access loans before the pandemic outbreak. It appears that most people left Kampala and came to the villages to engage in farming for survival. Apart from their poor saving culture, if at least 75% of the loans were repaid, the branch's loan portfolio would double that of 2019. Most farmers took loans ranging from UGX 500,000 (136 USD) to UGX 3,000,000 (818 USD) repayable in 12-18 months…

4.2.2. Extension services and capacity building

(a) Promotion of conservation agriculture

Seventy-nine percent of the farmers (79%) revealed that non-state actors advised them to adopt conservation agriculture in response to climate change. The majority of the respondents who vouched for conservation agriculture were female (41%) compared to male (38%) (Figure 6). Farmers understood conservation agriculture as farming methods that conserve, improve, and ensure the efficient use of natural resources, especially small pieces of land. This included mulching, planting of cover crops, use of soil bands, and application of organic fertilizers. Based on the t-test results, promoting conservation agriculture was perceived as the fifth role played by non-state actors in Rukiga (Table 4) by smallholder farmers. The International Crane Foundation is an NSA that plays a key role in the restoration of the Rushebeya-Kanyabaha wetland ecosystem, as it supports farmers in implementing conservation agriculture practices such as mulching, planting cover crops, crop rotation, and agroforestry to reduce soil erosion. Nature Uganda is another NSA that is involved in the conservation of the Rukiga watershed through the promotion of terracing, providing fast-establishing and maturing plants to hold the soil together, restoration of vegetation on hill slopes, and construction of contour bunds to control surface runoff and improve soil moisture infiltration. These roles include improving crop yield, preventing soil loss, and mitigating flooding and siltation of wetlands, among other environmental shocks caused by climate change.

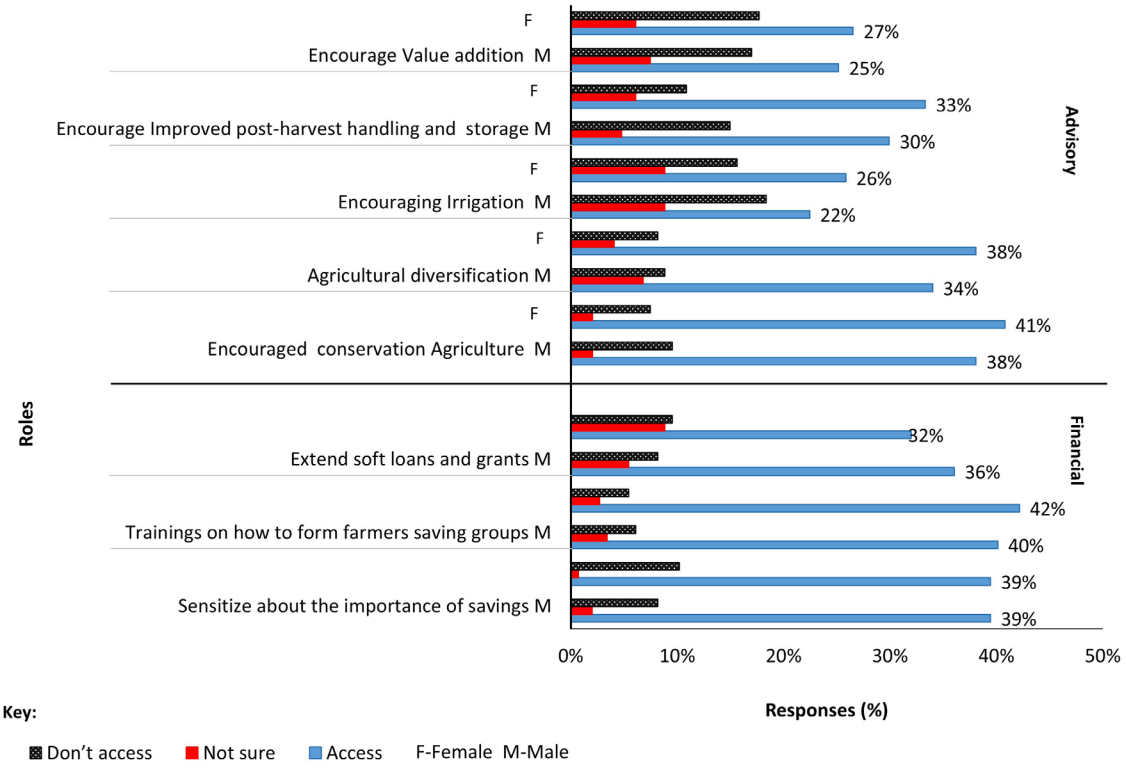

Figure 6. Accessibility to the roles played by non-state actors by female and male (n = 147).

(b) Diversification of agriculture

A cross-tabulation of responses on the role revealed that the majority (82%) of the respondents were aware of and affirmed the role played by females (38%) and males (34%) (see Figure 6). The t-test of this role revealed that agricultural diversification was perceived as the second-highest accessed advisory service ($M = 2.4$, $SD = 1$, $t = 17$, $p < 0.001$). NSA such as Compassion International, CARITAS, and Emmaus International promoted agricultural diversification among smallholder farmers who incorporated cash crops such as tea, apples, and coffee in the farmlands, and introduced the rearing of non-traditional livestock such as pigs and apiculture in the farming system. These activities boost smallholder farmers' incomes and increase food production, which buffers them from the shocks of climate change, including prolonged dry seasons and, consequently, crop failure, thus crippling farmers' livelihoods.

(c) Improved post-harvest handling

These include improved handling during harvesting and drying of maize, beans, and vegetables. Improved post-harvest handling included drying of crops, especially beans and maize, on tarpaulins, cemented grounds, storage in well-ventilated, pest/rodent-free stores/granaries, processing that involved winnowing, threshing and sorting, appropriate transportation, and marketing. These post-harvest practices have helped mitigate losses and ensure the quality of the produce to attract high prices. Sixty-three percent of the respondents reported improved postharvest handling of crops as an advisory service or role played by non-state actors such as USAID, Emmaus International, and CNV Uganda. Post-harvest handling also included value addition, such as proper sorting of seeds, and drying on clean surfaces, as reported by 52% of respondents.

(d) Encourage irrigation agriculture

Smallholder farmers who reported receiving encouragement to practice small-scale irrigation were minimal, and 48% of the respondents reported that they were not sure of the role being played by NSAs ($M = 3$, $SD = 1$, $t = 22$, $p < 0.001$).

5. Discussion

5.1. Household and on-farm dynamics of gendered climate adaptation

Women were the most affected by climate hazards in farming due to existing social and economic inequalities, such as unequal ownership rights over land, the primary resource in agriculture (Ampaire et al., 2020; Castelo et al., 2024; Oketcho et al., 2024). Unequal access to technology such as phones, radios, and televisions, which transmit weather broadcasts, especially in sub-Saharan societies accounted for the findings (Achandi et al., 2018; Misra et al., 2024; Mzimela & Moyo, 2025; Nosheen et al., 2023). A global review on climate change and gender by Sellers (2016) also revealed similar findings that women are more vulnerable to climate change risks in the agricultural sector worldwide due to limited land rights and major economic activities in households. However, based on their study in Nigeria, Olalekan et al. (2021) recommended membership to farmer-based organizations, and extension services to improve agricultural performance. Although findings on the use of drought-tolerant crops as an adaptation strategy to climate change are consistent with those of Tahiru et al. (2019) in northern Ghana. Findings on planting resilient crop varieties and cultivars, practicing conservation agriculture, diversification of agricultural activities, resilient and productive livestock breeds, and improved post-harvest handling were slightly surprising given the remoteness of the study area in tropical highlands compared to findings elsewhere. However, this can be attributed to the roles of NSA livelihood activities as depicted in the findings. Besides, the country's livelihood programs such as the Parish Development Model (PDM) and Emyooga among others have created room for women groups in agriculture to carry agricultural extensions (Lecoutere et al., 2023; Okello et al., 2023). Our results contrast with findings from other parts of Africa, such as Ghana, where Assan et al. (2018) reported that rural farmers struggle to adopt crop diversification and improved crop varieties due to remoteness limiting access to extension services. In our case, this highlights the role of the actor-network principle, where government livelihood programs and NSA programs are interwoven by smallholder farmers to enhance awareness and access to extension services, unlike scenarios where interventions are implemented in isolation.

In line with which gender preferred on-farm climate adaptation , findings of crop varieties and commercial cultivars perceived as most effective by women were not surprising, especially among rural farmers. This is because farmers especially women are now trying to move away from depending solely on small-scale and non-commercial agriculture to small-scale and commercial farming but also increase food stock. Demelash et al. (2021), International Fund for Agricultural Development (IFAD),) (2021), and Korres et al. (2016) revealed related findings. For instance, Korres et al. (2016) found that a possible solution to counteract the effects of climate change among smallholder farmers is to seek crop cultivars that are highly adaptable to enhance crop yield, especially under the current unreliable climatic conditions and possibly increase in pests and diseases. In a region like Kigezi highlands, increasing temperatures have been reported (Nadhomi et al., 2022). This could consistently have increased the chances of invasive insect survival in the area that affects crop yield (Gno-Solim Ela et al., 2023; Niyibigira et al., 2024; Skendžić et al., 2021). Also reports by international agencies such as International Fund for Agricultural Development (IFAD),) (2021)) report locally adapted and short-maturing cultivars to be more resilient to climate change stressors. This slightly aligns with the current findings in the Kigezi highlands where both female farmers believed that Indigenous maize varieties were more resilient to climate and provided sweet flour. This partly explains why Uganda's sectoral National Adaptation Plan for Agriculture (NAP-Ag) prioritizes promoting and encouraging highly adaptive and productive crop varieties and cultivars including Indigenous species for drought and rain-fed crop farming systems in Uganda (MAAIF, 2019). Therefore, NSA programs for breeding resistant varieties and/or using local varieties that are better adapted to pests and climate change will most likely boost food security among female smallholder farmers thus reducing the triple burden of crop failure, poverty, and famine in their households.

5.2. Non-state actors and gendered climate adaptation

Globally, scholars such as Yakubu et al. (2019), Kuyper et al., (2018), Nasiritousi et al., (2016), and Bäckstrand et al., (2017) have documented the crucial role of non-state actors (NSAs) in facilitating gendered adaptation. Sedegah et al. (2020) similarly highlighted that NSAs, including faith-based institutions, play a significant role in promoting financial adaptation mechanisms among smallholder farmers in rural Nigeria a finding that aligns closely with the experiences of the Kigezi Highlands. NGOs and other non-state actors have proven vital in strengthening the adaptive capacity of rural farming communities, especially in response to increasing climate hazards and related disasters (Tahiru et al., 2019). Likewise, lese et al. (2021) affirm the role of NSAs, including religious organizations, in supporting farmers to align their farming calendars with changing climate patterns. However, Ampaire et al. (2017) noted the limited access to agricultural advisory services and the prevailing policy-action gap in Uganda, which has hindered effective adaptation among female farmers who dominate the agricultural sector. They emphasized the need for improved linkages between farmers and NSAs to enhance policy implementation and build resilience among women groups for smallholders. One of the most effective strategies we found was supporting farmers to form saving groups. These groups not only created a social safety net but also facilitated access to information, group loans, and financial assistance resources that were especially critical during periods of climate stress. The social capital generated by these groups helped build cohesion and resilience. In South Africa, Tamako and Chitja (2017) found that such social capital significantly influenced household coping strategies and improved food security and adaptation outcomes.

In the context of the Kigezi Highlands, both men and women appreciated the benefits of savings groups, although with subtle differences in priorities. Women, often constrained by access to land and capital, gravitated toward group-based financial support as a means of securing small loans, improving food security, and initiating low-capital income-generating activities. Men, while also involved, were more likely to use such loans for expanding existing agricultural investments or initiating off-farm enterprises. These gendered preferences demonstrate how adaptation strategies are informed by gender roles, access to resources, and livelihood goals. Moreover, the availability of small loans enabled farmers particularly men to diversify into off-farm businesses, agro-processing, and small-scale livestock ventures. Such diversification enhances climate resilience by reducing dependence on climate-sensitive crop farming and promoting sustainable soil use. As Danso-Abbeam (2021) and Mbaziira et al. (2023) noted, rural non-farm

jobs significantly bolster the adaptive capacities of farmers in Uganda's drought-affected areas. This approach also mitigates soil overuse and degradation, especially in the highland regions. NGOs further supported diversification by promoting alternative livelihood options such as beekeeping, poultry farming, and small-scale enterprises, as emphasized by FAO (2014). These initiatives not only boosted household income but also reduced the pressure on natural resources. Knowledge dissemination and advisory services offered by NSAs played a crucial role in equipping farmers with climate-smart agricultural practices. Rosenstock and Nowak advocate for improved coordination between government and non-government actors to strengthen these advisory mechanisms. For instance, improved post-harvest handling practices enabled smallholder farmers to produce higher-quality outputs, leading to increased revenue and food security. NGOs assisted in setting up home-based storage units and provided technical support on proper grain handling, echoing the success stories from initiatives like the Zero Food Loss Initiative in Uganda (Costa, 2015).

Women, particularly those managing smaller plots or juggling household responsibilities, found post-harvest handling interventions especially beneficial, as they aligned with their priorities for household food security and income. This trend is consistent with findings from smallholder farmers in the Andes (Ballesteros & Isaza, 2021). The advisory roles of NSAs also extended to promoting conservation agriculture. Faith-based organizations, such as CARITAS, were particularly active in this domain, supporting practices like contour farming, trench digging, and the planting of grasses for erosion control in districts such as Rukiga. These efforts resonate with a study from Malawi (Chinseu et al., 2021), which documented how NGOs supported the use of compost manure, residue management, and soil conservation practices. Sulaiman (2017) also highlighted the role of organizations like the Agricultural Technology Transfer Institute (ATTI) in Costa Rica, which, through NGO partnerships, promoted climate-smart agriculture and soil conservation. This not only reduced erosion but also built long-term resilience among farmers. Agricultural diversification another advisory strategy helped promote the sustainable use of soil in highland areas. By encouraging farmers to integrate alternative crops or farming systems, NSAs contributed to both environmental sustainability and income diversification. The critical role of these advisory services is emphasized in the broader discourse on climate adaptation (FAO, 2014). Additionally, the focus on improved post-harvest handling by NSAs addressed critical value chain gaps, increasing profitability and reducing food loss (Chegere, 2018). These interventions while applicable to all were particularly appreciated by women and younger farmers who typically operate with limited access to land, and therefore focus more on household-level, high-efficiency adaptations.

Overall, the findings from this study reaffirm the significance of NSAs in promoting gender-responsive climate adaptation strategies. While men and women alike accessed NSA services, their utilization was shaped by gendered priorities and socio-economic realities. Hence, tailored interventions that recognize and leverage these gendered dynamics are essential for building equitable and effective resilience frameworks in climate-affected regions.

Achieving effective adaptation to climate change through household and on-farm strategies requires actor-network (s) with enhanced coordination between government and non-government bodies. These networks interact to shape the smallholders' resilience and adaptation outcomes (Anum et al., 2022), thus emulating the Actor Network theoretical principles. The ANT focuses on the complexity of reality and its inclusion of both human and nonhuman actors such as roles played by the non-state actors, state actors, community opinion leaders, and farmers. Non-human actors such as weather information systems, agricultural extension platforms, and social group access mechanisms play vital roles in shaping gendered climate adaptation responses, alongside human actors in the network such as government bodies. Fostering coordinated collaboration between state and non-state actors, while also investing in both human and non-human actors such as weather information systems, agricultural extension platforms, and inclusive social group networks. The series of progressive Development Plans (DPs) and climate policies in Uganda and beyond ought to institutionalize and support multi-actor networks that align with the principles of Actor-Network Theory (ANT) to strengthen gender-responsive climate adaptation at household and on-farm levels to enhance the adaptive capacity of smallholder farmers.

Conclusion

This study examined gendered household and on-farm climate change adaptation strategies among smallholder farmers in Uganda's tropical highlands, with a focus on the role of non-state actors (NSAs) in promoting gender-responsive adaptation. The findings reveal that NSAs particularly faith-based organizations, development agencies, and community-based networks play a significant role in facilitating adaptation by providing financial support, advisory services, and social mobilization. Female smallholder farmers identified savings schemes as the most effective adaptation strategy, followed by agricultural diversification and the provision of soft loans and grants. Compared to men, women showed greater involvement and efficiency in crop production and the marketing of agricultural produce. They favored planting resilient crop varieties and cultivars, especially indigenous types due to their ease of management and tolerance to pests and diseases. In contrast to more technical and on-farm-based practices such as soil and water conservation, women prioritized building social and financial capital as their primary adaptive mechanism.

These gendered preferences and actions are best understood through the lens of Actor-Network Theory (ANT), which emphasizes the complex interplay between human and non-human actors in shaping adaptation outcomes. In this context, human actors include farmers, community leaders, and organizations, while non-human actors such as weather information systems, agricultural extension platforms, and access to social networks significantly influence gendered adaptation practices. To support inclusive climate change adaptation, especially for women who are disproportionately affected, there is a need to enhance the coordination between state and non-state actors within well-structured actor networks. This should be stipulated in policy frameworks and development plans at national and local levels. Also, targeted efforts should focus on improving access to credit, information, and social networks, particularly for women with limited access to cultivable land since such resources regulate their adaptive capacity. Further research can explore the dynamics of actor networks over time demystifying the roles of particular state and non-state actors, and how these evolve to influence long-term adaptation outcomes for women and men in under-reported such as mountain environments that grapple with severe climate hazards. Future studies may adopt different research designs such as longitudinal, ethnographic, and citizen science approaches to increase the participatory reporting and long-term lived experience of the farmers across different spatial scales. Also, a study can document the dynamics and challenges NSAs in extending their support to rural farmers.

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Author contributions

CRediT: Yeeko Kisira: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, , Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; Martin Nabaasa: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, , Writing – review & editing; Flavia Nnyanzi: Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing; Irene Josephine Nayiga: Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing.

Ethical consideration

The research was approved by the Department of Geography, Geo-informatics and Climate Sciences Research Ethics Committee of Makerere University. We strictly adhered to ethical considerations, including participant consent, confidentiality, academic integrity, and harm avoidance. To ensure compliance, the corresponding authors engaged local leaders to discuss the study's goals and secure access to climate change hotspot areas. To maintain confidentiality, we did not report details of respondents. Participants agreed to publish their opinions in academic papers, assuming that their identities would be kept confidential.

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Data availability statement

The research data will be made available upon request from the corresponding authors.

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Appendix 1: Socio-demographic characteristics of the respondents

Socio-demographic profile		No. respondents	Percentage
Parishes	Kitanga	24	16.3
	Bucundura	24	16.3
	Nyakashebeya	24	16.3
	Kafunjo	26	17.7
	Rutengye	24	16.3
	Kitunga	25	17.0
Sex	Male	73	49.7
	Female	74	50.3
Age	18–24	9	6.1
	25–34	27	18.4
	35–44	24	16.3
	45–54	34	23.1
	<54	53	36.1
Marital status	Single	7	4.8
	Married	122	83.0
	Widowed	16	10.9
	Divorced	2	1.4
Education Level	Never attended	23	15.6
	Primary	15	10.2
	Secondary	79	53.7
	Technical/vocational	8	5.4
	University degree	22	15.0
Land size (acres)	<1	24	16.3
	1 to 5	94	63.9
	6 to 10	23	15.6
	>11	6	4.1

Source: Primary data.