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Determinants of Climate Change Adaptation Strategies among Smallholder Farmers in Nine African Mountains

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Declaration

I, (Nisha Jha), declare that this thesis is a result of my research investigations and findings. Throughout this study, I have conducted a comprehensive literature review and analysis to examine the adaptation strategies used by smallholder farmers in African mountains to address the impacts of climate change and the determinants that play a role in choosing those adaptation strategies. Sources of information other than my own have been acknowledged and a reference list has been appended.

This work has not been previously submitted to any other university for award of any type of academic degree. I was a part of the research project, 'Transformative Adaptation to Climate Change in African Mountains,' which was funded by the Mountain Research Initiative (MRI). This study will also be published online at https://mountainresearchinitiative.org/.

Signature: Nisha Jha

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Abstract

Mountain environments in Africa are facing increasingly rapid changes in temperature and rainfall patterns, which pose challenges for crop production. The growing literature has revealed that smallholder farmers use multiple adaptation strategies to respond to and reduce climate change impacts. However, more research on adaptation strategies and factors influencing the choice of those strategies still needs to be carried out, especially for mountains in Africa. Therefore, this study aimed to identify determinants of smallholder farmers' adoption of common adaptation strategies in the African mountains. A total of 1,350 farmer households were interviewed in nine mountains in seven countries. The results showed that the farmers primarily use on-farm strategies, including the use of improved varieties of crops, increased application of fertilisers and pesticides, soil and water conservation techniques and changes in planting dates. The farmers' choice of adaptation strategies was influenced by age, English or French proficiency, number of adults and children in the family, farm size, livestock ownership, village elevation, and market distance. These findings highlight the importance of considering the unique socio-ecological characteristics and resources of different mountain regions and the cultures of smallholder farmers in designing interventions to support their adaptation to climate change.

Keywords: adaptation; Africa; climate change; mountain regions; smallholder farmers

Research highlights

- On-farm strategies dominated adaptation choices among smallholder farmers
- Market distance and livestock ownership were the most important drivers of adaptation
- Adaptation interventions based on farming strategies should be given a priority
- Involving farmers to co-design future adaptation interventions is important

1. Introduction

African mountains are estimated to cover 11% of the world's total area, with a total land area of three million km^2 – most of which are in the continent's north-western, central, and eastern regions (Nsengiyumva, 2019; Kohler et al., 2015). The mountains act as water towers, providing water for domestic, industrial, irrigation and hydropower uses (Eckhoff et al., 2022). These landscapes are centres of biodiversity, wildlife habitat, forest and agricultural products, minerals, tourism, and sacred places (Eckhoff et al., 2022; Sayer et al., 2013). Tropical forests in African mountains are also carbon stores (Cuni-Sanchez et al., 2021). Thus, these mountains are vital to the well-being, livelihoods, and socio-economic development of millions of people in and around the mountain regions (Payne et al., 2020).

African mountains and their communities experience more rapid temperature changes than lower elevations because the rate of warming is amplified with elevation (Pepin et al., 2015). This makes climate change an especially concerning threat to these communities in highland environments, as it has the potential to negatively impact agriculture and cause food insecurity, particularly for smallholder farmers (Hassan & Nhemachena, 2008; Komba & Muchapondwa, 2012). Salami et al. (2010) defined smallholder farmers on the basis of land and livestock holdings, as farmers, who cultivate less than 2 hectares of land and own only a few heads of livestock. In a study carried out across Mount Kilimanjaro and the Udzungwa mountains in Tanzania, smallholder farmers reported reductions in crop yields and increased crop pests and diseases due to changes in rainfall and temperature (Kaganzi et al., 2021). The farmers in the Itombwe mountains of the Democratic Republic of Congo have also experienced an increase in hazards such as drought, soil erosion and livestock diseases and a decline in human health due to increases in cases of malaria and cholera (Amani et al., 2022). Likewise, a study from Bamenda highlands of Cameroon by Innocent et al. (2016) found that increased temperatures have reduced crop yields and increased food insecurity for farmers.

In the face of climate change, agricultural communities are responding with adaptations to reduce impacts by using different measures. These are often classified as ‘coping strategies’ when addressing post-disaster damages or as 'adaptation strategies' when they are applied before a hazardous climate event occurs (Morton, 2007). As found in various studies, smallholder farmers in Africa have embraced various adaptive strategies to strengthen their ability to address the effects of climate change (Aryal et al., 2021; Hassan & Nhemachena, 2008; Kaganzi et al., 2021; Mwalusepo et al., 2015). In general, the adaptation strategies used by smallholder farmers are divided into two groups: on-farm and off-farm strategies. The most common on-farm strategies are maintaining high agrobiodiversity and conducting soil or water conservation practices (Meldrum et al., 2018). Whereas two of the most prominent off-farm strategies are the diversification of livelihood through off-farm labour and the obtainment of membership in farmer's organisations which can facilitate technical help and access to improved seeds or inputs, credits, and subsidies (Cordoba-Vargas et al., 2019).

Adaptation is crucial to safeguard agricultural production and decrease the adverse impacts of climate change on farmers' livelihoods (Di Falco & Veronesi, 2013). Most farmers perceive the changes in climatic conditions and adjust their practices accordingly to minimise the detrimental effects of climate change on their farming activities (Deressa & Hassan, 2009). A systematic understanding of how farmers adapt and what factors influence their choice of adaptation strategies is necessary for the future design of adaptation policies (Aryal et al., 2021). Studies conducted by Maddison (2006) and Nhemachena and Hassan (2007) across different countries in Africa revealed that wealth, marital status, farming experience, age,

education, and gender of the head of household were the most common household characteristics influencing smallholder farmers' capacity to adapt to climate change adversities. Soil fertility, slope, and farm size were common farm characteristics influencing smallholder farmers' adaptation choices (Nhemachena & Hassan, 2007). In the farming community of Ethiopia's Dega and Woina Dega, the family size of the household head had a positive impact on a farmer's decision to choose more adaptation options, as there are more active household members available to use multiple adaptation strategies (Marie et al., 2020). Kangai et al. (2021) found that proximity to market centres plays a role in farmers' ability to adapt to the impacts of climate change. Specifically, they discovered that increased distance from market centres negatively impacts adaptation in Kenya. Several studies have been documented on area-specific climate change adaptation mechanisms and their adoption factors in different parts of Africa as it is further elaborated in the discussion. However, to our knowledge, there is limited literature that explicitly focuses on adaptation strategies in the African mountains and factors affecting adaptation choices.

This study aims to a) identify which adaptation strategies are used by smallholder farmers in African mountains and b) investigate the major determinants that influence farmers' choice of adaptation options at the household level. These insights will be a valuable contribution to developing interventions aimed at supporting farmers in their efforts to adapt to the impacts of climate change.

2. Methods

2.1 Study areas

The study was conducted in nine mountains in seven countries of Africa (Figure 1): the Bamboutos mountains (Cameroon), the Kigezi highlands (Uganda), the mountains of the Congo-Nile divide (Nyungwe national park in Rwanda and Kibira national park in Burundi), the Bale mountains (Ethiopia), Mount Kenya and the Aberdare range (Kenya) and Mount Kilimanjaro and the Udzungwa mountains (Tanzania).

Figure 1: a) Map of the study area b) Field image from the Bale mountains, Ethiopia c) Field image from Kibira national park, Burundi

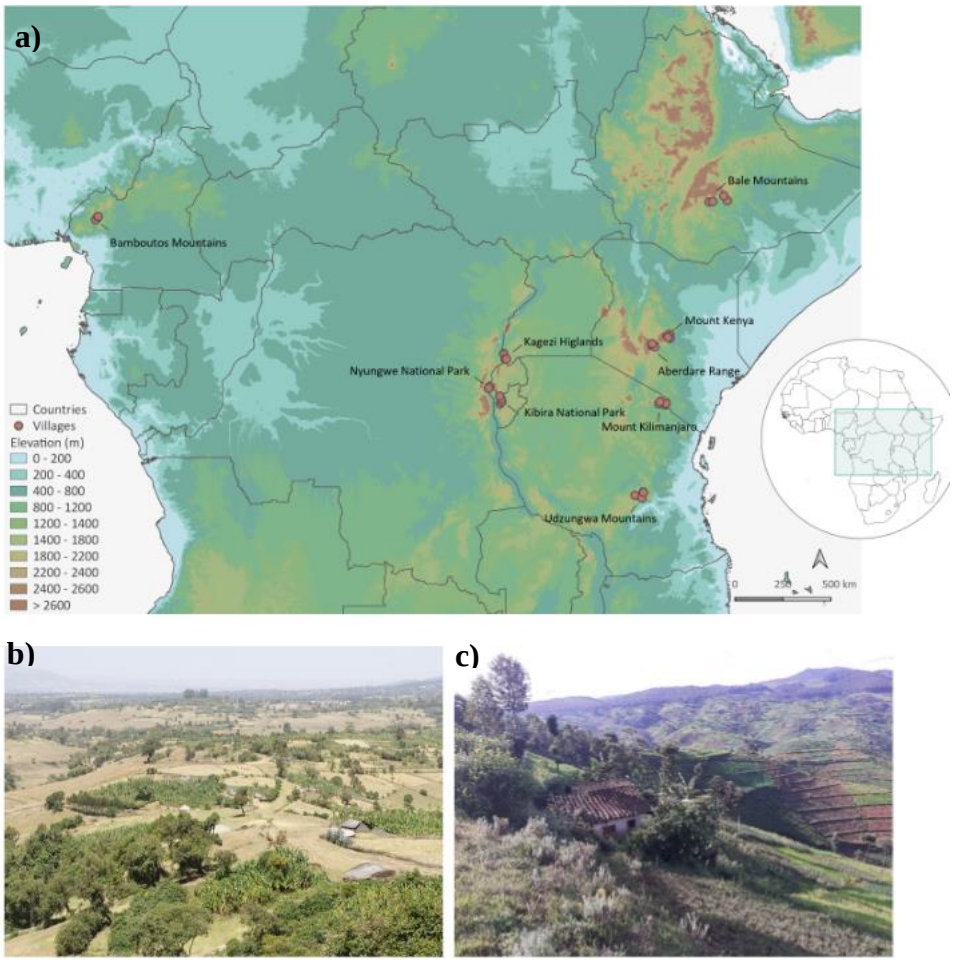

Image Credit: Abreham Berta Aneseyee (b) and Aline Nkurunziza (c)

These mountain regions were selected to represent different ecological (annual rainfall, rainfall distribution), socio-economic (e.g., ethnicity, distance to urban markets) and political contexts. Table 1 shows the ecological and socio-economical characteristics of each study area.

Table 1: Overview of the selected study areas, including annual rainfall, rainfall distribution, main crops, population density, most abundant ethnic groups, religion, and market distance*.

Mountain	Region	Annual rainfall (mm) and rainfall distribution	Annual temperature(°C)	Main crops	Population density (per km^2)	Most abundant ethnic group	Main religion	Market distance (km)
Bale mountains [1,2]	Southeast Ethiopia	1000 Bimodal rainfall regime	29.5	Food (maize, teff and mung bean) and cash crops (coffee and sesame)	32.10	Oromo	Islam	7–74
Mount Kenya [3]	Central Kenya	2300 Bimodal rainfall regime	17–22	Food (maize, beans, Irish potatoes) and cash crops (coffee, tea, bananas, avocados, macadamia and khat)	318	Meru	Christianity	0–6
Kigezi highlands[4]	South-western Uganda	2000 Bimodal rainfall regime	18	Food (maize, sweet potatoes, beans, and sorghum) and cash crops (coffee and Irish potatoes)	300	Bakiga	Christianity	6–24
Bamboutos mountains [5]	Western Cameroon	1780–2290 Unimodal rainfall regime	13–22	Maize, beans groundnut, Irish potatoes, avocado, yams, cassava, and vegetables (e.g., cabbages, carrots, and pepper)	350	Bamileke	Mostly christianity	5–15
Aberdare range[3]	Central Kenya	2300 Bimodal rainfall regime	17–22	Food (maize, beans) and cash crops (coffee, tea, bananas)	318	Kikuyu	Mostly christianity	0–3
Mount Kilimanjaro[6]	Tanzania	2000 mm Bimodal rainfall regime	15–30	Green banana, coffee, maize, beans, yams	3409	Chagga	Mostly christianity	3–22
Udzungwa mountains[6,7]	Tanzania	1400 mm Bimodal rainfall regime	17–30	Maize, beans and millet, and cash crops (Irish potatoes, onions, ground nuts)	30	Hehe	Mostly christianity	10–46
Kibira national park[8,9]	Burundi	1700 and 2000 Bimodal rainfall regime	24	Maize, bush beans, Irish potatoes, sweet potatoes	475	Tutsi and Hutu	Mostly christianity	0–15
Nyungwe national park [10]	Rwanda	1800 Bimodal rainfall regime	18.1	Maize, climbing beans, bananas, cassava	336	Tutsi and Hutu	Mostly christianity	4–7

* *Market distance - defined as the closest distance to urban centre from the village studied, calculated in QGIS*

1: Ofga & Benti, 2019; 2: Cuni-Sanchez et al., 2022; 3: Willkomm et al., 2016; 4: Twagiramaria & Tolo, 2016; 5: Ewane et al., 2021; 6: Kaganzi et al., 2021; 7: Platts et al., 2011; 8: Ndayizeye et al., 2020; 9: Nyairo et al., 2020; 10: Nkurunziza et al., 2023.

2.2 Data sources and data collection methods

The present study conducted a comprehensive literature review between August 2021 and December 2022 to evaluate the current state of evidence on the impacts of climate change and adaptation strategies in mountain regions in Africa. The literature search was performed using Google Scholar and Oria, the latter being the online library of the Norwegian University of Life Sciences. The search was conducted using keywords such as 'determinants', 'factors', 'adaptation strategies', 'African mountains', 'climate change', 'smallholder farmers', 'farming communities' and 'climate adaptation'. The scope of the study was limited to English language literature published between the years 2000 and 2022.

The data collection for this study was conducted between November 2020 and June 2021. Exploratory focus group discussions (FGDs) were held with elders in four villages (two in higher and two in lower elevations) in each study area to obtain information on the perceived changes in climate and its impacts on the biophysical environment. These discussions served to inform the design of the semi-structured questionnaires and to establish trust with the participants. The questionnaires were then administered to 150 randomly selected household heads using purposive sampling, with an equal representation of males and females, in each of the nine mountains. In total, 1,350 household data were collected from 36 villages. The questionnaires addressed household characteristics and assets, perceived changes in climate and impacts on the biophysical environment in their lifetime and adaptation strategies used to cope with or adapt to observed changes (Supplementary Material A). The questionnaire protocol followed the guidelines of the project Local Indicator of Climate Change Impacts (Reyes-García et al., 2020).

All participants in this study, including those in FGDs and interviews, were selected voluntarily and were first informed that the study aimed to better understand the perceived changes in climate and its impacts. Free, prior, and informed consent was obtained from all participants. The study adhered to the guidelines on ethical research outlined by the British Sociological Association (BSA, 2017) during the conduct of the interviews. The FGDs and interviews were facilitated by the co-authors and conducted in local languages for effective communication, including Oromo (Bale mountains), Swahili (Mount Kenya with some clarifications in English, Kikuyu or Meru), Rukiga (Kigezi highlands), Ngombale (Bamboutos mountains), Kikuyu (Aberdare range), Kichagga (Mount Kilimanjaro), Hehe (Udzungwa mountains), Kirundi (Kibira national park) and Kinyarwanda (Nyungwe national park).

2.3 Data analysis

The percentage of respondents per study area (150 respondents at each site) was the main unit of analysis. First, descriptive statistics were used to summarise the different adaptation options used by smallholder farmers for on-farm activities like crop production, crop diversification, livestock management and off-farm activities like livelihood diversification. Second, the determinants of farmers' adaptation decisions to climate change were analysed using a multinomial logistics regression (MNL). The MNL model was used based on previous literature on determinants of farmers' adaptation to climate change (Eshetu et al., 2020). This model helps to explore the degree and direction of the relationship between dependent and independent variables in climate change adaptation practices at the household level (Tiwari et al., 2014).

The model used was adopted from Agresti (1996):

$$\frac{Px}{1 - \mathrm{P}x} = \beta_0 + \beta_1 \mathrm{X}_1 \iota + \beta_2 \mathrm{X}_2 \iota \ldots\ldots \beta_\kappa \mathrm{X}_\kappa \iota$$

Where the subscript 'i' is the ith observation in the sample, Px is the probability of an event occurring for an observed set of variables $X_{i\ i.}$,i.e. the probability that the farmers adopt the adaptation practices, and (1- Px) is the probability of non-adoption. β_0 is the intercept term and β_1 , β_2 …. β_k are the coefficients of the explanatory variables $X_{1,}$ X_2 ….. $X_{k.li}$

The determinants affecting a farmer's adoption of adaptation strategies are combined effects of a range of factors such as demographic, socio-economic, and geographical characteristics in which farmers operate (Marie et al., 2020). The independent variables for this study include knowledge of English or French (a proxy for education), number of adults and children in the family, household head age, farm size, livestock ownership, village elevation, and market distance (see Table 2). These variables were selected based on a literature review and the experiences of the co-authors during the field trip. The dependent variables used in this study include the most used adaptation strategies as found in results.

Table 2. List of variables hypothesised to affect farmers' adaptation strategies.

Independent variables	Description	Expected effect
English/ French	If the household head can speak English/ French (0=no, yes=1)	Knowledge of national language is used as a proxy of education, which means more strategies used, more livelihood diversification. (1, 2)
Adults	Number of adults in the family (number)	More labour is available so there are greater chances of using labour-intensive strategies (e.g., soil conservation techniques) (3)
Children	Number of children in the family (number)	Greater need for food/schooling so, less likely to invest in 'expensive strategies' e.g., irrigation (4)
Age	Age of household head (years)	Older ones are less likely to engage in new technologies, new crops, or crop varieties (5, 6)
Farm size	Farm size (hectares)	Larger farms are more likely to invest in irrigation, agroforestry, and crop diversification (7)
Livestock	Number of livestock (number)	Livelihood diversification as livestock can be used as a source of income to be invested in other strategies (8,9)
Village elevation	Altitude of the village (in masl)	Higher elevation means less likely to use irrigation and soil and conservation practices (7)
Market distance	Distance to nearest market centre (in km)	Greater distances, fewer cash crops and vegetable farming because of additional transportation costs and less availability of seeds on time (10)

1 Gebru et al., 2020; 2: Deressa et al., 2009; 3: Aryal et al., 2021; 4: Personal communication, 2021; 5: Mwinkom et al., 2021; 6: Ajuang et al., 2016; 7: Eshetu et al., 2020; 8: Ojo & Baiyegunhi, 2020; 9: Ojo et al., 2021; 10: Kangai et al., 2021.

3. Results

3.1 Adaptation strategies

The most prevalent adaptation strategies were on-farm, and the average number of adaptation strategies used was 15, with each region having between 13 (Kigezi highlands and Nyungwe national park) to 17 (Udzungwa mountains) strategies in total (see Table 3). If only strategies used by more than 10% of respondents per study site were considered, the range was from 11 in Kigezi highlands to 15 in Udzungwa mountains.

The most commonly adopted on-farm adaptation strategies across all regions included using improved crop varieties (85% of total respondents), changing planting dates (72%), increasing the use of pesticides and insecticides (75% and 80% respectively), and adopting soil and water conservation techniques (74%). The most commonly adopted off-farm adaptation strategies across all regions included livelihood diversification through rearing animals (66%), diversifying livelihood through labour jobs (45%) and selling firewood (11%).

However, the percentage of respondents who had adopted prevalent adaptation strategies varied widely across the studied regions. For example, the soil and water conservation methods were highly used in most regions (98-75%), except for Bamboutos mountains, where only 9% of respondents reported using these techniques. The use of irrigation was much higher in some regions, such as Udzungwa mountains (81%) and Kibira national park (75%) than in Kigezi highlands (3%). The increased use of veterinary care and supplementary feed for livestock was higher in Mount Kilimanjaro (88% and 87% respectively) but lower in Udzungwa mountains (19% and 7% respectively).

Differences were also observed between the mountain regions. For example: changing farm location near streams was more common in Kibira national park (70%) and Udzungwa mountains (65%), while diversifying livelihoods by producing fruits or vegetables was more common in Mount Kenya (73%), Aberdare range (67%) and Nyungwe national park (72%). Some strategies were reported in only one or two regions, such as increasing farm size in Udzungwa mountains (47%) and selling timber in Bamboutos mountains (16%) and Mount Kenya (1%).

Table 3: Smallholder farmers' adaptive choices confronted with the adverse effects of climate change (%). Number of respondents in each mountain is 150 and total is 1350.

	Kibira (Burundi)	Kigezi (Uganda)	Bamboutos (Cameroon)	Mount Kenya	Abardere (Kenya)	Nyungwe (Rwanda)	Bale (Ethiopia)	Kilimanjaro (Tanzania)	Udzungwa (Tanzania)	Total percentage
Total number of adaptation strategies	**16**	**13**	**15**	**16**	**15**	**13**	**15**	**16**	**17**	
Adaptation strategies over 10% respondents per site	**14**	**11**	**12**	**14**	**14**	**12**	**14**	**14**	**15**	
On-farm strategies										
Change to improved varieties of crops	81	88	99	55	91	100	61	96	99	85
Change in planting dates	96	80	69	43	59	49	76	91	85	72
Increased irrigation	75	3	33	69	37	49	67	44	81	50
Sow seeds twice (if they die)	57	17	60	43	62	38	43	98	88	56
Increased use of fertilisers	95	38	98	98	93	83	59	73	81	80
Increased use of pesticides	90	60	91	99	87	48	41	73	84	75
Use of soil and water conservation methods	98	83	9	83	75	81	76	83	75	74
Grow different crops	29	54	0	13	42	0	82	0	40	29
Increased farm size	0	0	0	0	0	0	0	0	47	5
Change farm location (near stream)	70	3	47	5	18	0	0	7	65	24
Increased use of veterinary care for livestock	13	65	61	19	49	53	66	88	19	48
Increased use of supplementary feed for livestock	19	65	66	15	44	47	69	87	7	47
Off-farm strategies										
Diversify: labour	53	49	37	33	35	65	77	19	36	45
Diversify: business	0	0	0	0	0	0	35	60	38	15
Diversify: started rearing animals	69	25	81	81	43	73	90	99	35	66
Diversify: sell firewood	1	4	5	15	9	1	41	14	11	11
Diversify: sell timber	0	0	16	7	0	0	0	0	0	3
Diversify: vegetable/fruit production	10	0	0	73	67	72	0	37	0	29
Diversify: sell wild meat	1	0	1	0	0	0	7	1	0	1

3.2 Determinants of farmer's choice of adaptation strategies

The results of the MLR model revealed that the choice of different adaptation strategies was influenced by all eight factors considered in the model. The most important determinants among eight different factors across these mountain regions were livestock, and market distance, which affected increased use increased use of fertilisers, increased use of veterinary care for livestock, livelihood diversification by finding labour jobs and selling goods respectively (see Table 4). Only the factors at 0.1% level of significance were elaborated below.

Age was found to have a negative effect on the adoption of increased veterinary care for livestock but a positive effect on starting labour for livelihood diversification. Meanwhile, knowledge of English/French was found to be negatively associated with the adoption of improved crop varieties, growing different crops, increased use of fertilisers and pesticides on the farm, and producing fruits/vegetables for livelihood diversification. On the other hand, knowledge of English/French was found to be positively linked to finding labour jobs for extra income. The number of adults in the household was found to have a negative effect on growing different crops, increasing veterinary care, and diversifying livelihoods by finding labour jobs, and selling goods. The number of children in the family was found to be positively associated with increasing the use of fertilisers and negatively associated with increasing veterinary care and supplementary feed for livestock, and rearing animals for additional income.

Farm size was found to have a negative impact on the use of improved crop varieties, increased use of fertilisers and pesticides on the farm, changing planting dates, and diversifying livelihoods through selling goods. Livestock ownership was found to have a negative effect on increasing the fertilisers and pesticides on the farm, using soil and water conservation techniques, increasing veterinary care and supplementary feed for livestock, starting animal rearing, selling goods, and producing fruits/vegetables for livelihood diversification.

Village elevation was found to have a negative effect on the use of improved crop varieties and increased soil and water conservation methods. The market distance was negatively linked to growing different crops, increasing irrigation, and using fertilisers, changing planting dates, increasing veterinary care, diversifying livelihoods through finding labour jobs, and selling goods but positively linked to producing fruits/vegetables for livelihood diversification.

Table 4: Multinomial logistics regression model results of smallholders' choices of adaptation strategies, coefficients (p value). Significant p values at <0.001 are highlighted in bold.

	Change to improved varieties of crops	Grow different crops	Increased irrigation	Increased use of fertilisers	Increased use of pesticides	Change in planting dates	Use of soil and water conservation methods	Increased use of veterinary care for livestock	Increased use of supplementary feed for livestock	Diversify: labour	Diversify: started rearing animals	Diversify: selling goods*	Diversify: vegetable/fruit production
Age	-0.016	-0.001	0.004	-0.007	0.002	-0.008	-0.009	-0.019	-0.011	0.030	0.014	-0.007	0.007
	(0.005)	(0.771)	(0.362)	(0.192)	(0.643)	(0.070)	(0.107)	**<.001**	(0.020)	**<.001**	(<.003))	(0.218)	(0.119)
English/French	-1.205	-0.641	-0.312	-1.387	-0.975	-0.373	-0.303	0.020	-0.072	0.497	0.383	0.110	-0.711
	<.001	**<.001**	(0.021)	**<.001**	**<.001**	(0.011)	(0.095)	(0.884)	(0.619)	**<.001**	(0.007)	(0.514)	**<.001**
Adults	0.013	-0.156	-0.077	-0.125	0.080	0.034	-0.017	-0.148	-0.096	-0.134	0.002	-0.172	0.126
	(0.740)	**<.001**	(0.019)	(0.002)	(0.013)	(0.333)	(0.663)	**<.001**	(0.004)	**<.001**	(0.939)	**<.001**	(0.007)
Children	0.066	0.023	0.085	0.153	0.048	-0.041	-0.110	-0.222	-0.233	-0.049	-0.161	-0.089	0.010
	(0.062)	(0.443)	(0.006)	**<.001**	(0.102)	(0.209)	(0.006)	**<.001**	**<.001**	(0.086)	**<.001**	(0.007)	(0.772)
Farm size (Ha)	-1.070	-0.008	-0.076	-0.298	-0.190	-0.271	-0.035	-0.024	-0.051	0.080	0.064	-0.097	0.080
	<.001	(0.749)	(0.005)	**<.001**	**<.001**	**<.001**	(0.283)	(0.355)	(0.043)	(0.004)	(0.012)	**<.001**	(0.048)
Livestock	-0.043	-0.041	-0.316	-0.537	-0.759	-0.052	-0.627	-1.501	-1.402	-0.094	-2.085	-0.661	-1.075
	(0.816)	(0.780)	(0.030)	**<.001**	**<.001**	(0.737)	**<.001**	**<.001**	**<.001**	(0.515)	**<.001**	**<.001**	**<.001**
Village elevation	-0.541	-0.367	-0.186	-0.473	-0.126	-0.254	-0.91	0.203	0.061	-0.109	0.055	-0.062	-0.295
	<.001	(0.002)	(0.107)	**<.001**	(0.301)	(0.039)	**<.001**	(0.093)	(0.619)	(0.347)	(0.653)	(0.658)	(0.037)
Market distance	-0.342	-0.644	-0.957	-0.855	0.159	-0.691	0.342	-0.397	0.089	-0.392	0.177	-0.421	2.069
	(0.004)	**<.001**	**<.001**	**<.001**	(0.114)	**<.001**	(0.003)	**<.001**	(0.391)	**<.001**	(0.096)	**<.001**	**<.001**

**Note that, selling goods refers to selling firewood, timber and/or wild meat)*

4. Discussion

4.1 Adaptation strategies

The present study revealed that smallholder farmers in nine mountainous regions adopted a diverse range of on-farm and off-farm adaptation strategies. On-farm strategies were more prevalent than off-farm strategies in all regions, with the use of improved crop varieties, changing planting dates, using soil and water conservation methods, and increasing the use of pesticides and insecticides being the most prevalent. These findings are similar to other studies conducted in mountain regions In Africa, including Cameroon (Chiankem, 2022), Ethiopia (Alemayehu & Bewket, 2017), Tanzania (Kaganzi et al., 2021) and based on a review of 40 papers (as shown in Supplementary Material B).

The percentage of respondents who have adopted each strategy varied widely across the studied mountain regions. For example, increased irrigation ranged from 81% of the respondents in Udzungwa mountains to 3% in Kigezi highlands, which could be attributed to differences in water availability and access to irrigation technologies in different areas. Villages in Mount Kenya have water pipes, and farmers pay a small fee to access water. In contrast, farmers in the Bale mountains build small canals by hand for water diversion, making irrigation difficult when streams are far away. The use of soil and water conservation methods was high in most regions, except for Bamboutos mountains. This could be due to variations in soil types and topography in the different regions – or the issue of armed conflict and insecurity in this latter site, which is known to affect farmers' investment on their land (Baderha et al., in review). The farmers were also found to intensify veterinary care and supplementary feed use which was previously undocumented for Mount Kilimanjaro (Kaganzi et al., 2021) and Ethiopia (Belay et al., 2017; Tofu et al., 2022), but was mentioned in the mountains of northern Kenya (Cuni-Sanchez et al., 2018).

Notably, some strategies were only reported from one or two mountains, demonstrating that some climate change adaptation measures are location specific (Hinkel, 2011). For example, increasing farm size was only reported from the Udzungwa mountains and may not be possible in other regions due to high population density (see Table 1). Similarly, selling timber was only reported in Bamboutos mountains and Mount Kenya, which may be attributed to economic factors driving greater engagement in timber production in villages located closer to urban centres. These differences highlight the need for considering local contexts in mountain regions (Klein et al., 2019) when discussing farmers' adaptation.

Adaptation interventions are known to be most successful when tailored to the local environment and the farming system (Acevedo et al., 2020). Local people often have the capacity and means to determine how best to adapt to climate change, and participatory engagement between government agencies, NGOs, and local farmers can facilitate their adaptation (See et al., 2022). For example, one study participant in Mount Kilimanjaro noted that the government extension services provided them with seedlings of improved crop varieties that were not suitable for their farm, but they wanted improved varieties of banana to grow, indicating the importance of tailoring interventions to local needs.

4.2 Determinants of farmers' choice of adaptation strategies

Age and climate change adaptation

The results of this study showed a significant positive relationship between age and diversifying livelihood through finding labour jobs. This finding differs from the conclusion of a previous study by Aryal et al. (2021) in Kenya and Ethiopia, where the household head's age was negatively associated with seeking additional employment. The different findings of this study could be because older farmers in our study area viewed work as a necessity and used the skill outside farming to gain additional income.

In our study, the household head's age was found to be negatively associated with the decision to increase the use of veterinary care for livestock. This negative association may be explained by the fact that older farmers in our studied mountains may have a strong attachment to traditional methods and are less willing to embrace new technologies and practices, such as animal medication as also shown by Acevedo et al. (2020).

English/French and climate change adaptation

The results of this study showed that proficiency in English or French - the proxy for education - had a positive effect on diversifying livelihood through labour, which aligns with the findings of Ajuaye (2010) in Tanzania. On the other hand, the same factor had a negative effect on adaptation strategies such as using improved varieties of crops, growing different crops, increasing fertilisers and pesticides on the farm, and producing fruits/vegetables for livelihood diversification. This latter result contradicts the findings of previous studies in Ethiopia (Destaw & Fenta, 2021, Belay et al., 2017), which reported positive relationships between education and the adoption of all these adaptation strategies. This contradiction could be due to study design, sample size, or context differences, as Destaw and Fenta (2021) collected primary data from 147 households in different agroecological zones (highland, midland, and lowland). It highlights the need for further research to better understand the factors that influence adopting adaptation strategies in different contexts. It is also possible that the use of the English or French language as a proxy for education may not accurately reflect the level of education in the households.

Number of adults and climate change adaptation

This study showed that households with more adults had a significantly negative impact on growing different crops and increasing veterinary care for livestock, diversifying livelihood through entering the labour force, and selling goods. This finding disagrees with the result of Aryal et al. (2021), who found a positive relationship between the number of active labour members, changing farming practices, and seeking additional employment in Kenya and Ethiopia. This difference might be because the households in our study areas already have limited resources; the presence of more adults may place extra strain on the family and reduce the ability to invest in new crops, livestock care or capital for selling goods. It is possible that the additional adults in households are not surplus labourers who can participate in agriculture or other forms of employment, as they may already be employed elsewhere or unable to work due to their old age, something which could be explored in more detail.

Number of children and climate change adaptation

This study showed that the number of children positively impacted the decision to increase fertilisers on farms but negatively impacted the adoption of increased veterinary care and supplementary feed for livestock, as well as animal rearing for livelihood diversification. We hypothesised that families with more children might choose fewer expensive adaptation strategies such as increased use of irrigation due to increased expenses for covering the basic needs of the children. The families with more children were more likely to prioritise increasing fertilisers on the farm that directly helps in increasing crop yield, over other adaptation strategies. This could be explained by more children offering extra labour to work on the farm. The role of number of children on adaptation decision-making should be studied in more detail, as I was unable to find studies on the topic in Africa.

Farm size and climate change adaptation

The results of this study found that farm size had a significant negative impact on the use of improved crop varieties, increased fertilisers, and pesticides, change in planting dates, and producing fruits/vegetables for livelihood diversification. This finding differed from previous research that reported a positive relationship between land size and the adoption of drought-resistant varieties in Uganda (Atube et al., 2021) and disease-tolerant varieties in Tanzania (Mbwambo et al., 2021). One possible explanation is that the farmers in our study areas might not be wealthy enough to invest in expensive adaptation strategies. Larger farms typically require more resources to implement specific adaptation strategies, such as purchasing and applying fertilisers and pesticides or investing in new crop varieties, which demand more money. The farmers in this study may not have had access to the necessary financial resources to adopt these strategies. However, Kaganzi et al. (2021) suggests that wealthier farmers tend to have larger farms and more money to invest in agricultural inputs and technology. Further research is needed to better understand the impact of different farm sizes on adopting adaptation strategies. Additionally, larger farms may focus on either certain high-income crops or crops that are culturally attached to the community (Garibaldi & Turner, 2004), which results in a reduced focus on secondary crops like fruits and vegetables.

Livestock and climate change adaptation

This study results revealed that livestock ownership had a significant negative impact on the adoption of several adaptation strategies, including increased fertilisers, pesticides, soil and water conservation methods, increased veterinary care, and supplementary feed for livestock, as well as livelihood diversification such as animal rearing, selling goods, and producing fruits /vegetables. This finding is consistent with Aryal et al. (2021), who reported that households with more livestock were less likely to seek additional employment in Ethiopia and Kenya. However, other results contradict previous findings that have shown a positive relationship between livestock holding and the use of adaptation strategies such as soil and water conservation techniques and starting animal rearing for extra income in Ethiopia (Belay et al., 2017; Destaw & Fenta, 2021) and Kenya (Aryal et al., 2021). The farmers we interviewed across study regions have higher livestock assets on average, such as cows, sheep, pigs, goats, than the farmers interviewed in e.g., South Asia (Aryal et al, 2021). Hence, the farmers in our study areas may prioritise maximising their livestock income over implementing other adaptation measures based on the farm.

It is worth noting that the farmers who have livestock were even less likely to invest in increased supplementary feed or veterinary care for their livestock. This could be due to financial constraints that made purchasing additional feed or medication for their larger number of animals difficult.

Village elevation and climate change adaptation

This study results revealed that village elevation negatively affected the adoption of improved crop varieties, increased irrigation, and soil and water conservation methods. This finding aligns with Eshetu et al. (2020), who reported that highland areas in Ethiopia negatively impact the adoption of soil and water conservation methods. However, the present study differed with Destaw and Fenta (2021), who reported that farmers in the highlands and mid-highlands of Ethiopia are more likely to choose cultivation of improved crop varieties and terracing as soil conservation measure compared to those in the lowlands. The discrepancy in findings may be associated with the fact that our study did not interview farmers residing in villages at lower elevations. Our findings highlight the importance of considering elevation when promoting farmers' adaptation to respond to the changing climate.

Market distance and climate change adaptation

The results of this study found that market distance negatively affected the decision to grow different crops, increase irrigation, use fertilisers on the farm, change planting dates, increase veterinary care for livestock, and diversify livelihoods by finding labour jobs and selling goods. These findings are supported by Destaw and Fenta (2021) and Marie et al. (2020), who reported in Ethiopia that households with market access have a higher probability of adopting climate change adaptation measures than households lacking market access. Our results also indicated a positive relationship between market distance and vegetable/fruit farming. Households closer to the market are more likely to assess the necessary inputs and opportunities to engage in on-farm and off-farm activities (Hassan & Nhemachena, 2008).

Table 5: Determinants influencing the choice of adaptation strategies reported by other studies on smallholder farmers' adaptation to climate change in Africa.

	Study 1 (Ethiopia)	**Study 2 (Kenya)**	**Study 3 (Uganda)**	**Study 4 (Cameroon)**	**Study 5 (Tanzania)**	**Study 6 (Ethiopia)**	**Study 7 (Ethiopia)**	**Study 8 (Ethiopia)**	**Study 9 (Tanzania & Kenya)**	**Study 10 (Rwanda)**	**Study 11 (Tanzania)**	**Study 12 (Ethiopia & Kenya)**	**Study 13 (11 African countries)**
Age	*	*	*	**	NS	*	NS	**	NS	NS	NS	*	NS
Education	*	*		NS	*		*	**	NS	NS	NS	**	
Family size		NS	*		**	NS	NS	NS	NS	NS		**	**
Number of adults								A				A	
Number of children													
Farm size	*	*	*		*	**	*	*		NS	**	**	**
Livestock							*	**				**	
Village elevation	**				*			**					
Market distance		*	*			NS	NS	*		*		**	**

***significant (p < 0.01): *significant (p < 0.05): NS- not significant: Empty values- factors not studied in the study area: A- active labour*

Study 1: Eshetu et al. (2020); Study 2: Kangai et al. (2021); Study 3: Atube et al. (2021); Study 4: Ngoe et al. (2019); Study 5: Ajuaye (2010); Study 6: Marie et al. (2020); Study 7: Belay et al. (2017); Study 8: Destaw & Fenta (2021); Study 9: Mwalusepo et al. (2015); Study 10: Nyirandorimana et al. (2020); Study 11: Mwambo et al. (2021); Study 12: Aryal et al. (2021); Study 13: Hassan & Nhemachena (2008)

5. Study limitations

This study has several limitations that need to be acknowledged. Firstly, it is limited to an English language literature review, meaning only English language studies and research were considered. This limitation is important to note because the study could have included relevant research and studies in other languages, such as French. As Nuñez and Amano (2021) have highlighted, monolingual searches can lead to an incomplete understanding of the topic being researched and potential bias in the results.

Secondly, the data were collected only from certain ethnic groups in each mountain region. While the findings of this study provide valuable insights specific to each area, they may not be representative of the larger population in different ethnic groups. As Ingty (2017) emphasised, effective adaptation planning may require knowledge regarding exchanges between local farmers and researchers and between communities in mountain regions. Thus, future research should consider a sample population size from different ethnic groups in areas where more than one ethnic group is present.

Thirdly, the statistical analysis was conducted at a specific level of significance (0.1%), which may limit the comparability of our results with those from other studies that use different levels of significance. Comparing results across studies that use different levels of significance can lead to misleading conclusions and increase the risk of Type I errors (Cumming, 2013). Type I error, also known as a false positive, occurs when a researcher rejects the null hypothesis when it is true (Ellis, 2010). Therefore, caution should be exercised when making such comparisons, and a focus on comparing the magnitude and direction of the estimated effect sizes of the results across studies is recommended.

Fourth, there is limited literature that paid attention to the influence of intra-household dynamics, gender roles, and relations on adaptation decisions (Fisher & Carr, 2015; Ngigi et al., 2016). The data collected in this study had a disproportionate number of married female respondents living in male-headed households compared to female-headed households. Their views do not necessarily represent the experiences and perspectives of female-headed households in understanding how the gender of the household head affects the choice of adaptation strategies (Fuwa, 2000). Future research should aim to sample female-headed households to provide a more exhaustive gender perspective.

Fifth, we did not investigate the efficiency or sustainability of the adaptation strategies mentioned by respondents. Our goal was to identify and document the various strategies being used by smallholder farmers in response to the challenges posed by climate change, but not to assess the efficiency of the strategies mentioned. We acknowledge that some of these strategies may have potential drawbacks, such as limited long-term viability or negative impacts on the environment. For instance, the increased use of chemical fertilizers to enhance crop yields may provide short-term benefits, such as increased production, but can have negative impacts on the environment, such as pollution and soil degradation (Lal, 2015). Instead, our findings of multiple adaptation strategies (Table 3) could serve as a starting point for further research and exploration into the efficiency and sustainability of these strategies, as well as their potential for wider adoption and implementation in other mountain regions.

Sixth, it should also be noted that the data collection for this study was not conducted personally by the primary investigator but rather by other researchers in the studied countries. This step was necessary due to the COVID-19 pandemic, which prevented the primary investigator from conducting fieldwork in person. However, it must be acknowledged that the data collection

was carried out by a researcher from the same ethnic group in each studied mountain region who spoke the local language and could be considered an insider. A standardised questionnaire was used across sites and webinars were arranged to coordinate results interpretation. Therefore, we consider that the researchers' positionality was uniform across the research process. Positionality, defined as an individual's worldview and the position they adopt about a research task and its social and political context, is integral to the process of qualitative research, as is the researcher's awareness of the lack of stasis of their own and others' positionality (Foote & Bartell, 2011; Holmes, 2020;).

6. Implications of the findings

This study's findings have significant implications for policies and practices concerning climate change adaptation in African mountain regions. It emphasises how farmers are more drawn towards finding options to respond to the impacts based on farming rather than shifting to another livelihood. This result implies a need to prioritise and support these local adaptation efforts on farms. Focusing on the farmers' perspective and their preferred strategies, policies and practices can better address these communities' specific challenges in adapting to climate change. Additionally, investing in on-farm adaptation measures can increase the resilience and self-sufficiency of these communities in terms of food security, potentially reducing the need for external interventions in the future. The prioritisation of on-farm strategies highlights the need to support farmers in their adaptation efforts rather than assuming that they rely solely on external interventions (Woroniecki et al., 2020).

The study's findings emphasise the importance of tailored and location-specific adaptation strategies for African mountain regions. This highlights the need for targeted support, including financial, technical, and capacity-building assistance, for smallholder farmers in these areas. The unique conditions and resources of each mountain region should be considered when developing adaptation strategies, such as taking into account population density when promoting the increase in farm size or the feasibility of selling timber in specific areas (Hallegatte, 2009; Kohler & Masseli, 2009). Further research is necessary to understand the most effective adaptation strategies for different mountain communities and contexts. There may also be opportunities for cross-regional collaboration and sharing of adaptation techniques among these communities.

The study highlights the importance of market access in adopting adaptation strategies. Improving market access through policies and programmes is crucial, particularly in remote mountain regions where market infrastructure is limited (Ferris et al., 2014). This may involve building or improving roads and transportation networks to support the unique terrain of these areas.

One important implication of the study is the need to use a ‘science with society’ participatory and transdisciplinary approach to identify promising future adaptation pathways (Steger et al., 2021). This approach brings together actors from various sectors and disciplines, including farmers, policymakers, and researchers, to engage in knowledge co-production and co-create solutions that are context-specific and responsive to the needs of local communities. By appreciating cultural values and building trust between local peoples and other stakeholders, this approach can provide a deeper understanding of differentiated climate hazard exposures, vulnerabilities, and risks that farmers face and help to design more effective and sustainable adaptation strategies (IPCC, 2018). Therefore, it is vital for future research and policy efforts

to adopt such an approach to co-create and implement effective and locally relevant adaptation strategies.

7. Conclusion

In conclusion, this study summarises smallholder farmers' adaptation strategies to climate change and the determinants that impact the adaptation options of those farmers in nine African mountain regions. The study found that farmers primarily use on-farm adaptation strategies such as changing to improved crop varieties, increasing the use of fertilisers and pesticides on the farm, employing soil and water conservation techniques, and changing the planting dates. The study also found that farmers use off-farm activities such as livelihood diversification through labour and rearing animals, but to lesser extents. The results also indicated that socio-economic and geographical factors, such as the age of the household head, knowledge of English/French, number of adults and children in the family, household farm size, livestock ownership, village elevation and proximity to markets, influence the adaptation strategies chosen by smallholder farmers, which aligns with previous studies but with varying effects. Overall, this study highlights the need for location-specific, context-specific, and community-based policies and interventions that consider the unique socio-ecological characteristics and resources of different mountain regions and the cultures of smallholder farmers.

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Supplementary Material A. Semi-structured questionnaires.
Note that focus-group discussions were used to create a list of ten items wealthy households commonly own in each study area, and thus lists were not the identical. The lists in questions 15 and 16 of the questionnaire were modified according to responses in the focus group discussions.

1. Village name

2. Household composition (adults M and F)

3. Household composition (children)

4. Owner of house

5. Age of farmer

6. Farm size (ha)

7. List animals your household has

8. Does your household have any of these items? Tractor / Cow) / >5 ha land / >6 children / Motorbike / Car / Television /Radio / Mobile phone / Cement house with metal roof / Grinder / Car / Shop / Water pump / Farm

9. Does your household belong to a farmer association? If yes, which one

10. Which activities are important to your household?

11. Have you heard of the term climate change, and can you explain what it means?

12. If so, who explained this phenomenon to you?

13. How do you determine when to sow your seeds?

14. Compared to when you were a teenager and started farming, which of the following climatic changes have you noticed in your village? Increased temperatures (dry season)/ Increased temperatures (rainy season)/ Reduced rainfall (long rains)/ Late start long rains/ More dry spells (long rains)/ More showers (dry season)/ More extreme floods/ More extreme droughts/ Fewer foggy days/ Less frost/ Increased wind (rainy season)/ Fewer hailstorms/ Reduced stream flow (rainy season)/ More landslides (rainy season)/ More soil erosion (rainy season)

15. Compared to when you were a teenager and started farming, which of the following impacts changes have you noticed in your village? Lower yields (maize)/ Lower yields (beans)/ Lower yields (coffee)/ Lower yields (banana)/ Lower yields (potatoes) / Lower yields (onions) / Increased pests/diseases (maize) / Increased pests/diseases (beans) / Increased pests/diseases (coffee)/ Increased pests/diseases (banana)/ Increase pests/diseases (potatoes) / Mango bears less fruit / Cows produce less milk / Cows have more diseases / Goats have more diseases / Pigs have more diseases / People are less healthy.

16. Which of the following adaptation strategies have you used? Crop change (millet)/ Change to improved variety (maize)/ Change to improved variety (beans) / Change to improved variety (potatoes) / Change to improved variety (onions) /Change to improved variety (banana) / Change to improved variety (coffee) / Increased shade in coffee / Increased farm size/ Changed farm location (near stream) / Increased irrigation / Sow seeds earlier / Sow seeds later / Sow seeds twice (if they die) / Increased use soil conservation / Increased use fertiliser / Increased use pesticide / Increased use veterinary care (cows) / Increased use veterinary care (goats) / Increased use veterinary care (pigs) / Increased use feed (cows) /Increased use feed (goats) / Increased use feed (pigs) / Diversify: sell firewood / Diversify: NTFPs (hunting, honey) Diversify: labour / Diversify: started rearing animals / Diversify: vegetable/fruit production / Diversify: trading animal products/ Diversify: small business / Diversify: tourism

Supplementary Material B. Reviewed literature.

Table 1: Adaptation strategies reported by other studies on-farmers' perceptions in Tanzania.

Adaptation strategies	**This Study**	1 (Kili)	2 (Kili)	3 (Kili)	4 (Kili)	5 (Udz)	6 (Par)	7 (Udz)	8 (Ulu)	9 (Usa)	10 (Do)	11 (Par)	12 (SH)
On-farm strategies													
Change to improved varieties of crops	X	x					x			x		x	
Change in planting dates	X						x			x			
Increased irrigation	X	x	x			x	x	X	x	x		x	x
Sow seeds twice (if they die)	X												
Increased use of fertilisers	X		x				x			x			
Increased use of pesticides	X		x			x	x					x	
Use of soil and water conservation methods	X	x	x				x		x	x			
Grow different crops	X												
Increased farm size	X							X					
Change farm location (near stream)	X											x	x
Off-farm strategies													
Increased use of veterinary care for livestock	X												
Increased use of supplementary feed for livestock	X												
Diversify: labour	X	X											
Diversify: business	X												
Diversify: started rearing animals	X										x		
Diversify: sell firewood	X												
Diversify: sell timber													
Diversify: vegetable/fruit production	X	X											
Diversify: sell wild meat	X												
Diversify: tourism	X												

Kili: Kilimanzaro; Udz: Udzungwa; Ulu: Uluguru; Do: Dodoma; Par: Pare; SH: Southern highlands of Tanzania.

1: Mwakalila, 2014; 2: Mulangu & Kraybill, 2013; 3: Sébastien, 2010; 4: Wagner et al., 2021; 5: Schumacher, 2018; 6: Velempini & Smucker, 2016; 7: Kassian et al., 2017; 8: Msaliwa et al., 2017; 9: Nyasimi et al., 2017; 10: Naess, 2013; 11: Paavola, 2008; 12: Kangalawe, 2017

T**able 2: Adaptation strategies reported by other studies on-farmers' perceptions in Kenya.**

Adaptation strategies	**This Study**	1 (Siaya)	2 (Mount Kenya)	3 (Mount Kenya)	4 (Murang'a)	5 (Cherangani hills)	6 (Taita hills)	7 (Taita hills)
On-farm strategies								
Change to improved varieties of crops	x	x		x	x	x	x	x
Change in planting dates	x	x		x	x	x		x
Increased irrigation	x	x			x	x		x
Sow seeds twice (if they die)	x							
Increased use of fertilisers	x	x	x		x	x	x	
Increased use of pesticides	x				x		x	x
Use of soil and water conservation methods	x	x	x		x	x	x	x
Grow different crops	x	x	x	x				x
Increased farm size		x		x			x	
Change farm location (near stream)	x							
Off-farm strategies								x
Increased use of veterinary care for livestock	x							
Increased use of supplementary feed for livestock	x				x			
Diversify: labour	x			x			x	
Diversify: business								
Diversify: started rearing animals	x	x			x	x		
Diversify: sell firewood	x			x		x		
Diversify: sell timber	x							
Diversify: vegetable/fruit production	x			x		x		
Diversify: sell wild meat								
Diversify: tourism								

1: Musafiri et al., 2022; 2: Mairura et al., 2021; 3: Jairo & Korir, 2019; 4: Asayehegn et al., 2017; 5: Nyberg et al., 2020; 6: Motaroki et al., 2021; 7: Mwalusepo et al., 2015

Table 3: Adaptation strategies reported by other studies on-farmers' perceptions in Uganda.

Adaptation strategies	This Study	1 (northern)	2 (Rwenzori)	3 (Isozi)	4 (Kigezi)	5 (Kapchorwa)	6 (Mt.Elgon)
On-farm strategies							
Change to improved varieties of crops	x	x	x	x	x	x	x
Change in planting dates	x		x	x		x	x
Increased irrigation	x			x			x
Sow seeds twice (if they die)	x						
Increased use of fertilisers	x	x		x			
Increased use of pesticides	x	x					
Use of soil and water conservation methods	x	x	x	x	x	x	x
Grow different crops	x	x				x	
Increased farm size							
Change farm location (near stream)	x						
Off-farm strategies							
Increased use of veterinary care for livestock							
Increased use of supplementary feed for livestock	x						
Diversify: labour	x						x
Diversify: business							x
Diversify: started rearing animals	x						x
Diversify: sell firewood	x						x
Diversify: sell timber							
Diversify: vegetable/fruit production							x
Diversify: sell wild meat							
Diversify: tourism							

1: Atube et al., 2021; 2: Zizinga et al., 2015; 3: Mugagga et al., 2015; 4: Twagiramaria & Tolo, 2016; 5: Tiyo et al., 2015; 6: Bomuhangi et al., 2016

Table 4: Adaptation strategies reported by other studies on-farmers' perceptions in Rwanda.

Adaptation strategies	**This Study**	1 (Kibirizi)	2 (Buragama)
On-farm strategies			
Change to improved varieties of crops		x	x
Change in planting dates			x
Increased irrigation			x
Sow seeds twice (if they die)			
Increased use of fertilisers			x
Increased use of pesticides	x		x
Use of soil and water conservation methods	x	x	x
Grow different crops			x
Increased farm size			
Change farm location (near stream)			
Off-farm strategies			
Increased use of veterinary care for livestock	x		
Increased use of supplementary feed for livestock	x		
Diversify: labour	x		
Diversify: business			x
Diversify: started rearing animals	x		
Diversify: sell firewood	x		
Diversify: sell timber			
Diversify: vegetable/fruit production	x		
Diversify: sell wild meat			
Diversify: tourism			

1: Clay & King, 2019; 2: Nyirandorimana et al., 2020

Table 5: Adaptation strategies reported by other studies on-farmers' perceptions in Burundi. No previous literature has been found based on mountains in Burundi until December 2022.

Adaptation strategies	This Study
On-farm strategies	
Change to improved varieties of crops	x
Change in planting dates	x
Increased irrigation	x
Sow seeds twice	x
Increased use of fertilisers	x
Increased use of pesticides	x
Use of soil and water conservation Methods	x
Grow different crops	x
Increased farm size	
Change farm location (near stream)	x
Off-farm strategies	
Increased use of veterinary care for livestock	x
Increased use of supplementary feed for livestock	x
Diversify: labour	x
Diversify: business	
Diversify: started rearing animals	x
Diversify: sell firewood	x
Diversify: sell timber	
Diversify: vegetable/fruit production	x
Diversify: sell wild meat	x
Diversify: tourism	

Table 6: Adaptation strategies reported by other studies on-farmers' perceptions in Cameroon.

Adaptation strategies	**This Study**	1 (Bamenda)	2 (Rumpi hills)	3 (Western highlands)	4 (Western highlands)	5 (Rumpi hills)
On-farm strategies						
Change to improved varieties of crops	x	x	x	x		
Change in planting dates	x	x	x	x	x	x
Increased irrigation	x			x	x	
Sow seeds twice (if they die)	x					
Increased use of fertilisers	x	x		x	x	x
Increased use of pesticides	x		x	x	x	x
Use of soil and water conservation methods	x	x	x	x	x	
Grow different crops						x
Increased farm size						x
Change farm location (near stream)	x			x		
Off-farm strategies						
Increased use of veterinary care for livestock	x					
Increased use of supplementary feed for livestock	x					
Diversify: labour	x					x
Diversify: business				x		x
Diversify: started rearing animals	x					
Diversify: sell firewood	x					
Diversify: sell timber	x					
Diversify: vegetable/fruit production						
Diversify: sell wild meat	x					
Diversify: tourism						

1: Innocent et al., 2016; 2: Beckline et al., 2016; 3: Chiankem, 2022; 4: Bruckmann et al., 2022; 5: Ngoe et al., 2019

Table 7: Adaptation strategies reported by other studies on-farmers' perceptions in Ethiopia.

Adaptation strategies	**This Study**	1 (Mad)	2 (Wor)	3 (Tig)	4 (Tig)	5 (Hara)	6 (NS)	7 (Amba)	8 (Amh)	9 (CRV)	10 (Jim)
On-farm strategies											
Change to improved varieties of crops	x	x	x	x		x			x		x
Change in planting dates	x	x	x	x	x	x		x		x	x
Increased irrigation	x	x		x	x		x			x	x
Sow seeds twice (if they die)	x										
Increased use of fertilisers	x							x	x	x	x
Increased use of pesticides	x								x		x
Use of soil and water conservation methods	x		x	x	x	x	x	x	x	x	x
Grow different crops	x		x		x	x	x	x			
Increased farm size											
Change farm location (near stream)											
Off-farm strategies						x					
Increased use of veterinary care for livestock	x										
Increased use of supplementary feed for livestock	x										
Diversify: labour	x										
Diversify: business	x	x					x				
Diversify: started rearing animals	x	x						x			
Diversify: sell firewood	x										
Diversify: sell timber											
Diversify: vegetable/fruit production		x	x								x
Diversify: sell wild meat	x										
Diversify: tourism											

Mad: Madugga; Wor: Woreda; Tig: Tigray; Hara: Hararghe; NS: North Shewa; Amba: Ambassel; CRV: Central Rift Valley; Jim: Jimma

1: Alemayehu & Bewket, 2017; 2: Bewket, 2012; 3: Kahsay et al., 2019; 4: Gebrehiwot & van der Veen, 2013; 5: Tesfaye & Seifu, 2016; 6: Hilemelekot et al., 2021; 7: Destaw & Fenta, 2021; 8: Tofu et al., 2022; 9: Belay et al., 2017; 10: Eshetu et al., 2020

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