Omer *et al. Discover Sustainability* (2025) 6:1012
https://doi.org/10.1007/s43621-025-01543-9

Discover Sustainability

RESEARCH

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Perceptions of climate variability, adaptation strategies, and their determinants among smallholder farmers in the Gabiley Region, Somaliland

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Abstract

Climate variability and change significantly threaten agricultural yields in developing countries, particularly Somaliland, where crop production is susceptible to rain and temperature fluctuations. This study assessed the perceptions of climate variability, adaptation strategies, and their determinants among smallholder farmers in the Gabiley Region, Somaliland. A mixed-methods approach involved a survey of 193 farming households, selected via multistage sampling, focus group discussions, and key informant interviews. Farmers' perceptions and adaptation strategies were analyzed using descriptive statistics, logistic regression models were used to identify determinants of adaptation, while qualitative data were analyzed thematically. Findings revealed strong farmer awareness of climate change (86.5%), with most reporting rainfall declines and temperature increases, and 93.8% experiencing droughts. Despite this, a significant adaptation gap persists, with an average adoption rate of 45% across various adaptation strategies. While adjusting crop calendars, drought-tolerant cultivation, crop rotation, and terracing show high adoption, crop diversification, soil and water conservation, water harvesting, irrigation, and 'advanced practices' exhibit low adoption. Key determinants that positively influenced adoption included education level, household size, employment status, market access, and direct experience with climate events. This study emphasizes the urgent need for effective context-specific climate adaptation. Recommendations include enhancing farmer education on climate adaptation, improving access to markets and climate information, and providing targeted support for the adoption of crucial but underutilized strategies, such as drought-tolerant crop varieties, water harvesting, and soil conservation techniques, to bolster agricultural productivity, food security, and livelihoods in the Gabiley region.

Keywords Adaptation strategies, Climate variability and change, Smallholder farmers, Gabiley, Somaliland

1 Introduction

Climate change poses a profound threat to the survival and economic well-being of nations worldwide, regardless of their developmental stage [34]. Globally, agricultural production suffers from reduced crop yields and diminished harvest quality, undermining food security and economic stability (Intergovernmental Panel on Climate Change [IPCC], [20]). This threat is particularly acute for small-scale farmers, who face significant vulnerabilities stemming from alterations in temperature regimes, precipitation patterns, and the escalating intensity and frequency of extreme weather events, all of which directly impact their crop and livestock production systems [37]. In Africa, where agricultural practices are intrinsically linked to prevailing climate and weather conditions, climate change demonstrably reduces overall farming productivity, jeopardizing livelihoods and exacerbating existing challenges [18]. East African nations are particularly vulnerable, with adverse effects on agricultural output impacting a significant portion of the region's gross domestic product (GDP [11, 36]) Given the widespread reliance on rain-fed agriculture in these areas, the majority of farming systems are inherently susceptible to climate-related disruptions, emphasizing the urgent need for adaptive strategies. The Sustainable Livelihoods Approach (SLA, developed by DFID [10]) provides a valuable framework for understanding climate change adaptation decisions by emphasizing the role of various assets (natural, physical, human, financial, and social, institutions, and processes in shaping adaptive capacity and livelihood outcomes.

Somaliland's heavy reliance on nomadic herding renders it exceptionally vulnerable to climate change, particularly drought. The United Nations Development Programme (UNDP) estimates that approximately 70% of the Somali population depends on climate-sensitive agriculture and pastoralism [35]. The country's arid to semi-arid climate, characterized by low precipitation, further intensifies this vulnerability. Climate change, alongside environmental degradation, recurrent droughts, and floods, poses a significant threat to livelihoods, food security, and poverty reduction [1, 28]. The failure of Somaliland's rainy season leads to drought, soil depletion, reduced vegetation, and declining crop yields. Increased climate variability has severely affected livelihoods, causing crop failures, livestock losses, food insecurity, water shortages, and displacement [2, 28, 29]. Consequently, food insecurity and malnutrition now affect nearly one-third of Somaliland's population, with conditions worsening since 2010 [29]. Assessments by the Integrated Food Security Phase Classification [19] and the Food Security and Nutrition Analysis Unit of Somalia [13] indicate that food insecurity and malnutrition are disproportionately prevalent in rural areas, particularly among female-headed, less educated, and low-income households [13, 19].

In the Marodijeeh and Gabiley regions, agropastoral communities rely on livestock and crop production. Limited herd sizes and crop yields make these communities economically vulnerable to climatic and socioeconomic shocks [2]. The region has experienced a reduction in the extended rainy season, and temperature trends indicate a warming climate, with rising annual maximum and minimum temperatures [32]. These climatic shifts have resulted in decreased yields for staple crops such as sorghum, maize, beans, and millet, primarily attributed to altered rainfall patterns, drought, increasing temperatures, reduced soil moisture, and increased insect populations [32]. Indeed, a recent spatiotemporal analysis of agricultural drought severity across Somaliland, encompassing these regions, confirms significant temporal and spatial variability in drought conditions, with severe stress observed between 2015 and 2018 [27]. The findings underscore the escalating severity and frequency of climate variability, making it critical to develop targeted strategies aimed at reducing the sensitivity of farmers and pastoralists to these changes and promoting sustainable livelihoods [35].

Perceptions of climate change and variability play a crucial role in shaping the adaptation strategies employed by smallholder farmers across various regions. Research conducted in India highlights a growing awareness of increasing drought frequency and intensity, particularly among marginal farmers who rely heavily on rainfall and possess limited adaptive capacity [22, 23]. In addition, smallholder farmers in sub-Saharan Africa face significant challenges due to climate variability and change, leading them to adopt various adaptation strategies, including adjustments to crop and livestock management practices, diversification of livelihoods to reduce reliance on agriculture, and modifications to land-use management techniques to enhance sustainability [12]. Similarly, studies conducted in East Africa, specifically Ethiopia, indicate that farmers perceive a distinct trend of increasing temperatures coupled with decreasing rainfall patterns, often associating these changes with local deforestation practices [3, 31]. However, despite these broader regional insights, there remains a notable gap in empirical research specifically focusing on the perception of climate variability among smallholder farmers in Somaliland, particularly in the Gabiley region.

In response to these perceived changes, farmers actively implement a range of adaptation measures to mitigate the adverse impacts of climate variability. These include the diversification of crop varieties to enhance resilience to changing conditions, the adoption of improved irrigation techniques to ensure reliable water access, and the cultivation of drought-tolerant crop species to minimize yield losses during periods of water scarcity [3, 31]. Within Somaliland, smallholder farmers also face significant challenges due to climate variability and change, necessitating diverse adaptation strategies such as adjustments to crop and livestock management, diversification of livelihoods, and modifications in land-use practices [12, 29]. Specifically, households utilize mobility to access resources in different areas, livelihood diversification to reduce reliance on agriculture, and small-scale trading as coping mechanisms to generate income [29], while argo-pastoralists employ strategies like livestock diversity to reduce vulnerability to disease and traditional early warning systems to prepare for extreme events [2]. Although empirical research in Somaliland has documented adaptation strategies at a national level, specific adaptation strategies employed by smallholder farmers in the Gabiley region remain largely unexplored, hindering the development of targeted support programs.

While adaptation strategies in Somaliland are documented to some extent, empirical research on the determinants influencing these adaptations is notably lacking, making it difficult to design effective policies and interventions. Studies conducted in regions adjacent to Somaliland, such as Ethiopia and Kenya, offer valuable insights into potential influencing factors that could be relevant in the Somaliland context. For instance, in Ethiopia, adaptation practices like crop diversification, soil conservation, and tree planting are significantly influenced by factors such as education level, family size, gender dynamics, age of the household head, livestock ownership, and overall household income, highlighting the complex interplay of socioeconomic factors [7, 17]. Furthermore, access to agricultural extension services, providing farmers with information and support, also plays a significant role in promoting the adoption of adaptation strategies

[17]. Similarly, research conducted in southwestern Ethiopia indicates that factors such as gender, age, family size, education level, livestock holding, access to extension services, and access to reliable weather information significantly affect the choice of adaptation responses, underscoring the need for a holistic approach to understanding adaptation decisions [16]. Kenyan studies emphasize the importance of cultivating drought-resistant crop varieties as a key adaptation strategy, influenced by both the age of the farmer and their overall farming experience, while also highlighting the crucial role of education, access to extension services, farm size, and access to credit facilities in enhancing overall adaptive capacity and resilience [25]. These findings from neighboring regions underscore the need for dedicated research to understand the specific determinants shaping adaptation decisions among smallholder farmers in Somaliland, particularly in the Gabiley region, to inform the design of effective and targeted interventions.

Climate variability significantly affects the predominantly agricultural and pastoral Gabiley region of Somaliland, impacting smallholder farmers' crop yields, food security, and livelihoods. The existing literature explores climate variability, drought, food security, and adaptation strategies in Somaliland [26, 28, 29, 32]. However, despite these broader regional insights, there remains a notable gap in empirical research specifically focusing on the perception of climate variability among smallholder farmers in Somaliland. Although empirical research in Somaliland has documented adaptation strategies at a national level, specific adaptation strategies employed by smallholder farmers in the Gabiley region remain largely unexplored. While adaptation strategies in Somaliland are documented, empirical research on the determinants influencing these adaptations is notably lacking. Addressing this pronounced lack of localized understanding for the Gabiley region is the primary impetus for this research. Therefore, this study examines the perceptions of climate variability, the adaptation strategies, and the determinants of adaptation adoption among smallholder farmers in the Gabiley region of Somaliland, addressing the central question: How do smallholder farmers in the Gabiley region of Somaliland perceive climate variability, what adaptation strategies do they employ in response, and what key socioeconomic, institutional, and environmental factors determine the adoption of these strategies? Understanding these strategies and their determinants is crucial for developing effective support mechanisms and policies that enhance resilience in agriculture, ensuring sustainable livelihoods and food security in Gabiley.

2 Materials and methods

2.1 Study area

The smallholder farmers' villages selected for this study are located within the Gabiley region, specifically in western Somaliland, approximately 32 km west of Hargeisa, the capital of Somaliland [30]. Hargeisa is the capital and largest city of Somaliland, an autonomous region in the Horn of Africa that declared independence from Somalia in 1991, a declaration that has not been internationally recognized [30]. The Gabiley Region shares borders with the Marodijeeh region to the east, the Awdal region to the west, Ethiopia to the south, and portions of Awdal to the north. Most inhabitants of the region are agro-pastoralists. Gabiley serves as the primary agricultural area for Somaliland, producing up to 85% of the country's food supplies. The region is renowned for its agricultural and farming industries and is the principal location where most Somaliland crops are cultivated [26]. These communities have a long history of cultivating crops that parallels that of the neighboring Ethiopian Somali region. Early in the twentieth century, settlements were established along the dry rivers in the two regions, and farmers began growing sorghum and maize as subsistence crops. Even today, sorghum and maize remain the principal rainfed crops grown in this area with very limited inputs, mainly in the form of labor and seed [2]. The region's soils vary from sandy and sandy loam with low water holding capacity and poor nutrient content to heavy clays with high water holding capacity and relatively favourable fertility along the westernmost parts adjoining the Ethiopian border [2] (Fig. 1).

2.2 Research design, approach, and sampling procedure

This study used a mixed-methods design. The quantitative component adopted a cross-sectional survey design to assess perceived climate variability and adaptation strategies among smallholder farmers in the Gabiley region of Somaliland. Concurrently, qualitative data were collected through focus group discussions and interviews with the key informants. Both quantitative and qualitative data streams were analyzed separately and then integrated during the interpretation phase to provide a more comprehensive understanding and facilitate the triangulation of findings. The integration of both methodologies, although with a primary quantitative emphasis on specific analyses, facilitated the examination of a wider range of research questions and the collection of essential information [9]. According to the Ministry of Agriculture and Development in Somaliland, approximately 3500 farmers have been registered in the Gabiley region, although the total number is estimated to exceed 7000.

A multistage sampling procedure was employed to select both the study area and participating smallholder farmers. Initially, three of the seven districts in the Gabiley region, Arabsiyo, Gabiley, and Alleybaday, were selected using a simple random sampling method. Subsequently, two villages within each of the three districts were selected. This purposive selection was informed by considerations of resource constraints and the necessity of capturing a diverse range of climate variability experiences, resulting in the inclusion of six villages in the study. Finally, questionnaires were distributed to the smallholder farmers in each village. To ensure a representative sample of farmers from these specific locations, this study utilized systematic random sampling techniques to select individual farmer households within each of the six chosen villages.

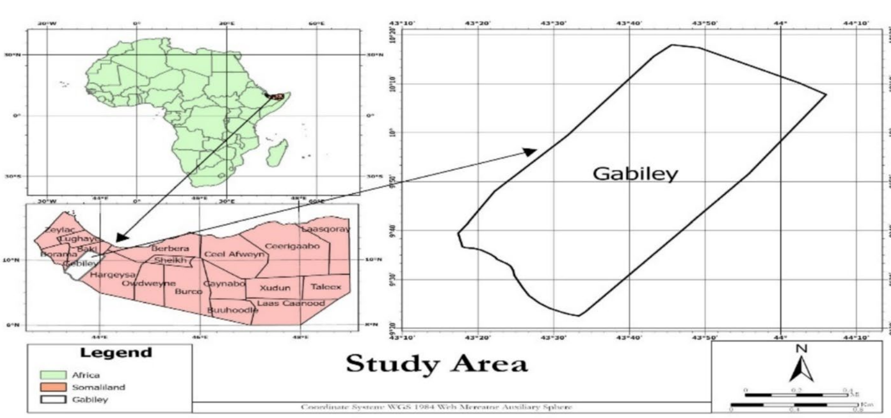

Fig. 1 Location of the study area

A total of 193 smallholder farmers were surveyed using Yamane's simplified formula to calculate the sample size, assuming a confidence level of 95% and a margin of error of 7%. This 7% was chosen to balance statistical reliability with fieldwork feasibility, given the logistical and financial constraints of reaching a highly dispersed rural population. Similar studies in comparable East African rural settings have used margins between 5 and 10%, under similar constraints [7, 24]. Design effect was not used to determine the sample size in this study.

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

$$\mathrm{n} = \frac{3500}{1 + 3500\left(0.07^{2}\right)} = 193$$

where n is the sample size, N is the total number of registered farmers, and e is the error margin.

2.3 Data sources and collection methods

This study employed a mixed-methods approach, integrating quantitative and qualitative data to investigate perceptions of climate variability, adaptation strategies, and their determinants among smallholder farmers in the Gabiley region, Somaliland. Primary quantitative data were collected through structured and semi-structured questionnaires administered to a representative sample of smallholder farming households. These questionnaires elicited information on: (a) demographic characteristics of household heads; (b) perceptions of climate change and variability; (c) observed changes in rainfall and temperature patterns; (d) perceived impacts of climate variability on agricultural production and livelihoods; and (e) adaptation strategies adopted by households. Secondary quantitative data, comprising (2010–2022) of cereal production, was obtained from the Food Security and Nutrition Analysis Unit [14]. These secondary data were used to analyze historical climate trends, providing empirical evidence of climate change in the region and serving as a baseline for comparison with farmer perceptions.

To triangulate the quantitative findings from the household surveys and cereal production, qualitative data were collected through two focus group discussions (FGDs) with smallholder farmers and semi-structured interviews with key informants, including experienced farmers (n = 4) and agricultural officers (n = 3). These qualitative data collection methods provided richer insights into local perceptions of climate change, detailed descriptions of adaptation practices, and contextual understanding of the barriers and opportunities for effective adaptation, thereby enhancing the validity and reliability of the study's findings. The integration of quantitative and qualitative data facilitated a more comprehensive and nuanced analysis of climate variability and adaptation in the Gabiley region.

2.4 Data analysis

The sociodemographic characteristics, perceptions, perceived effects, and adaptation strategies of smallholder farmers regarding climate change and variability were analyzed using descriptive statistics (frequencies, means, ranges, percentages, and standard deviations) in STATA version 17.0. Three separate binary logistic regression models were employed to determine the factors associated with the adoption of specific climate change adaptation strategies. Each model focused on a distinct adaptation strategy chosen based on its potential to enhance resilience within local agroecological settings and its relevance to farmers in the study area. For each of these three models, the dependent variable was a binary indicator of whether a farmer had implemented a particular adaptation strategy (1 = yes, 0 = no). This approach of analyzing determinants for individual, impactful strategies provides more nuanced insights than a single, general adoption measure, and is consistent with existing studies that seek a detailed understanding of adoption drivers [6, 17, 31]. This binary specification is considered appropriate for examining the influence of independent variables on the probability of dichotomous outcomes, as supported by Kothari [21]. The independent variables, summarized in Table 1, were selected based on a comprehensive review of the existing literature, identification of key theoretical constructs, and a thorough understanding of climate adaptation strategies employed by rural farming communities in the region. Qualitative data from focus group discussions and interviews were coded and analyzed for themes that were contextualized, enriched, and triangulated with the quantitative findings.

This study models the adoption of climate change adaptation strategies (Y_i) among smallholder farmers using logistic regression:

$$\pi_i = P\left(Y_i = 1|\mathbf{X}_i\right) = 1/\left(1 + \exp\left[-\mathbf{X}_i'\boldsymbol{\beta}\right]\right).$$

Where:

Y_i = 1 if a farmer adopts adaptation strategies, 0 otherwise.

π_i is the probability of adoption.

$\mathbf{X}_i$ is a vector of 15 explanatory variables (socioeconomic and environmental factors).

$\boldsymbol{\beta}$ is a vector of regression coefficients.

Odds ratios are calculated as $\exp(\beta_j)$, representing the change in odds of adoption for a one-unit change in variable X_j.

Table 1 Description of the dependent and independent variables

Dependent variables	Description
Adaptation strategies	Dummy (1 = Using the Adaptation Strategy, 0 = Not Using the Adaptation Strategy)
Independent variables	
Gender	Dummy (Male = 1, Female = 0)
Age	Continuous (years)
Education	Dummy (1 = able to read and write, 0 = Unable to read and write)
Household size	Continuous (number)
Employment	Dummy (1 = employed, 0 = unemployed)
Access to market	Dummy (has market access, 0 = no market access)
Livestock ownership	Dummy (Yes = 1, No = 0)
Awareness of Climate Change	Dummy (Yes = 1, No = 0)
Source of information	Categorical (0 = family, 1 = government, 2 = development agents, 3 = fellow farmers, 4 = radio, 5 = seminar/training)
Experience with Drought	Categorical (1 = experienced drought, 0 = no experience)
Frequency of Climate Variability	Categorical (0 = Once every 5 years, 1 = Once every 4 years, 2 = Once every 3 years, 3 = Once every 2 years, 4 = radio, 5 = every year)
Rainfall pattern change	Categorical (increased = 1, decreased = 0)
Early onset of the rainy season	Categorical (Yes = 1, No = 0)
Cessation of the rainy season	Categorical (Yes = 1, No = 0)
Temperature pattern change	Categorical (increased = 1, decreased = 0)

Logistic regression models were evaluated for their suitability for the dataset. Multicollinearity was assessed using Variance Inflation Factors (VIF) and intercorrelations, with all predictors meeting the acceptable criteria. The Hosmer–Lemeshow test showed good model fit for all models, and Omnibus Tests of Model Coefficients confirmed the collective explanatory power of the predictors in each case. The Wald test assessed the significance of the individual predictor variables, confirming the robustness of the models for analyzing adaptation determinants.

3 Results

3.1 Socio-demographic of the respondents

The sociodemographic characteristics of 193 smallholder farmers participating in the study on climate variability and adaptation strategies in the Gabiley region of Somaliland (Table 2) offer key insights. The average respondent age was 49 years, with households averaging seven members, reflecting diverse family structures. Regarding education, 41% were literate and 59% illiterate, underscoring the challenges in disseminating climate adaptation information. The gender distribution shows that 71% of respondents are male, suggesting that men primarily serve as household heads or decision-makers in agriculture. Employment rates were also low, with only 15% employed, highlighting economic vulnerability. Only 15% of the respondents were employed, highlighting economic vulnerability. Furthermore, only 31% of households had access to markets, limiting their capacity to sell produce and acquire the necessary resources, thereby hindering their ability to adapt to climate variability. Livestock ownership, at 77.72%, is common and crucial to livelihood and potentially serves as an asset for climate adaptation. Overall, these findings demonstrate that smallholder farmers in Gabiley face significant obstacles in climate adaptation. Low literacy rates, high unemployment, limited market access, and heavy reliance on livestock pose significant challenges to resilience in the face of climate variability.

3.2 Perception of respondents on climate change and variability

The perception of climate change among respondents was notably significant, with 86.5% acknowledging its existence (Table 3). Regarding information sources, 37.8% of farmers relied on radio broadcasts, while 24% consulted fellow farmers. Most respondents

Table 2 Sociodemographic characteristics of respondents. *Source*: *Field Data 2024*

Continuous Variable	Obs	Mean	SD	Min–Max
Age	193	49.45	12.20	18—71
Household size	193	6.94	2.22	2—12
Dummy variables		**Frequency**		**Percent**
Education status Able to read and write		80		41.45
Unable to read and write		113		58.55
Gender—Male		137		70.98
Female		56		29.02
Employment—Employed		30		15.54
Not employed		163		84.46
Market access—Has market access		59		30.57
No market access		134		69.43
Livestock ownership—Yes		150		77.72
No		43		22.28

Table 3 Perception of climate change of respondents. *Source*: *Field Data 2024*

Perception of climate change		Frequency	Percent
Awareness of climate change	No	26	13.5
	Yes	167	86.5
Rainfall in the last 30 years	Increase	24	12.4
	Decrease	169	87.6
In the onset of rainfall	No	85	44.0
	Yes	108	56.0
The cessation of rainfall	No	52	26.9
	Yes	140	72.5
Temperature pattern change	Decrease	53	27.5
	Increase	140	72.5
Extreme climate observations	No	12	6.2
	Yes	181	93.8
Experience with drought	No	15	7.77
	Yes	178	92.23

(87.6%) reported a decline in rainfall over the past 30 years, while 72.5% observed rising temperatures, highlighting increasing climatic challenges. Furthermore, 56% had noted changes in the onset of rainfall and 72.5% reported changes in its cessation, complicating agricultural activities. Extreme climate events, such as droughts, are universally experienced, with 93.8% of farmers reporting their occurrence. Specifically, 92.23% of the respondents have faced droughts in recent years, with more than two-thirds experiencing extreme climate events annually. The high frequency of severe weather conditions exacerbates the challenges faced by farmers, emphasizing the need for effective adaptation strategies.

A significant portion (84%) of the respondents identified local indicators of declining rainfall, such as increased drought frequency, crop yield losses, and shifts in the timing of rainy seasons, all of which disrupt farming productivity. In terms of rising temperatures, 56.5% of the respondents noted key indicators, including the emergence of previously unseen diseases and new plant and animal species, along with shifts in the crop calendar, highlighting the growing impacts on agriculture and biodiversity. Regarding the causes of climate change, 42.49% of respondents attributed it to deforestation, while 35.23% identified a combination of factors including deforestation, poor land management, and acts of God.

Focus group discussions and key informant interviews strongly corroborated the quantitative trends observed in Table 3. Focus group discussions with smallholder farmers in the Gabiley region revealed a consistent and deeply felt perception of climate variability, mirroring the statistically significant trends observed in the quantitative data (Table 3). Participants consistently described a constellation of interconnected changes, including decreasing rainfall, increasing temperatures, shifting rainfall patterns (characterized by erratic and unpredictable onset and distribution), and a rising frequency of drought events. These accounts, grounded in the lived experiences of farmers, provide a crucial context and nuanced understanding of quantitative trends, highlighting the tangible impacts of climate variability on farmers' agricultural practices and livelihoods. Key informant interviews with agricultural experts corroborated smallholder farmers' perspectives regarding the changing climate landscape of the Gabiley region. Experts echoed the observations of decreased rainfall, rising temperatures, and shifting rainfall patterns, validating the lived experiences of farmers and reinforcing the validity of both qualitative (FGD) and quantitative (Table 3) findings. Furthermore, experts have emphasized the escalating severity and frequency of drought events, highlighting the long-term implications for agricultural sustainability and food security in the region. These expert perspectives offer a broader, scientifically informed perspective on observed climatic shifts, strengthening the evidence base for the need for targeted adaptation strategies.

3.3 Perceived effects of climate change and variability of respondents

The respondents were asked to rate the perceived effects of climate variability on a Likert scale of 1–5 (Table 4). The data reveal the significant challenges faced by smallholder farmers in the Gabiley Region of Somaliland. Crop failure emerged as a primary concern, with 74.08% strongly agreeing and 25.4% agreeing that it was a critical consequence of climate variability. This finding indicates widespread anxiety regarding agricultural productivity. Similarly, reduced crop yields were widely recognized, with 51.30% agreeing and 47.66% strongly agreeing, further emphasizing the gravity of the issue. Persistent drought was also identified as a major challenge, with 50.78% strongly agreeing and 46.63% agreeing, highlighting the recurrent nature of drought and its impact on water and agricultural resources. Additionally, delayed rainfall was identified as a significant concern by respondents, with 62.2% agreeing and 29.53% strongly agreeing. This delay is understood to cause substantial disruptions to farm cycles, including shortened planting periods and compromised crop development.

Thematic analysis of qualitative data indicated that smallholder farmers in the Gabiley region perceive climate change and variability as a significant and interconnected set of challenges to their agricultural livelihoods. Farmers consistently reported experiencing diminished agricultural productivity, primarily manifested as increased crop failure and reduced yields, particularly in staple crops such as maize and sorghum. This perceived decline in productivity was frequently attributed to increasingly prolonged and unpredictable drought periods, which in turn exacerbated existing vulnerabilities related to land degradation and soil fertility depletion, as corroborated by both focus group discussions with farmers and key informant interviews with agricultural experts conducted for this study. The combined effects of these factors result in significant farming difficulties,

Table 4 Perceived effects of climate variability experienced. *Source*: Field Data 2024

	Freq	Percent
Crop failure		
Disagree	1	0.52
Agree	49	25.4
Strong agree	143	74.08
Reduced crop yield		
Disagree	2	1.04
Agree	99	51.30
Strong agree	92	47.66
Persistent drought		
Disagree	5	2.59
Agree	90	46.63
Strong agree	98	50.78
Delayed rainfall		
Disagree	7	3.6
No comment	9	4.7
Agree	120	62.2
Strong agree	57	47.5

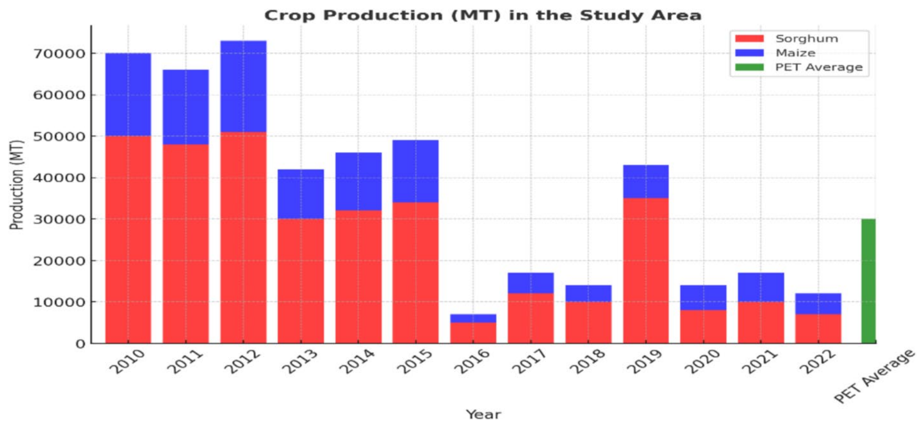

Fig. 2 Cereal production 2010–2022 in the study area.
Source: FSNAU [14]

Table 5 Adoption of climate change adaptation strategies among smallholder farmers

Adaptation strategy	Frequency	Percentage (%)
Adjusting crop calendars	164	84.97
Cultivating drought-tolerant crops	135	69.95
Enforcing crop rotation practices	118	61.14
Establishing terracing systems	101	52.33
Embracing crop diversification strategies	93	48.19
Practicing soil and water conservation methods	85	44.04
Implementing water harvesting & irrigation techniques	72	37.31
Utilizing varied crop types and varieties	36	18.65
Engaging in tree-planting initiatives	29	15.03
Employing improved seeds	27	13.99

impacting household food security, economic stability, and overall well-being. These qualitative findings were corroborated by quantitative data (Table 4), revealing a statistically significant negative correlation between farmers' perceptions of climate change and their reported crop yields, highlighting the detrimental effects of climate variability on agricultural practices in the Gabiley region.

Cereal production from 2010 to 2022 in Fig. 2 strongly aligns with the perceived effect of climate variability held by smallholder farmers in the Gabiley Region, Somaliland, as it visually demonstrates the impacts of changing climate on agricultural productivity. This fluctuating and generally declining production trend support farmer-reported observations of reduced rainfall, rising temperatures, and erratic rainfall patterns, all of which significantly disrupt traditional farming practices. Notably, the graph's depiction of years with drastically low cereal yields corroborates the widespread farmer experiences of increasingly frequent and severe droughts, reinforcing the urgent need for effective adaptation strategies to safeguard the livelihoods of vulnerable agricultural communities.

3.4 Adaptation strategies of respondents

An Analysis of climate change adaptation strategies among smallholder farmers (N = 193) in the Gabiley Region revealed significant disparities in adoption rates. The average adoption rate across all strategies was 45% (Table 5), with the highest uptake for adjusting crop calendars (84.97%), demonstrating a significant reliance on temporal adjustments and other common practices, such as drought-tolerant cultivation (69.95%), crop rotation (61.14%), terracing systems (52.33%), and crop diversification (48.2%), reflecting a focus on maximizing resource utilization and minimizing vulnerability to climate variability. However, the low adoption rates of Practicing Soil and Water Conservation Methods (44.04%) and water harvesting and irrigation techniques (37.3%) highlight the potential lack of access to water resources and irrigation infrastructure, which ultimately limits the effectiveness of other adaptation measures. Furthermore, the relatively low adoption of advanced practices such as diverse crop varieties (18.65%), tree-planting initiatives (15.03%), and improved seeds (13.99%) suggest a need for increased access to knowledge, technology, and resources to promote the adoption of more sophisticated and potentially impactful adaptation strategies. Addressing this gap in adaptation practices through targeted interventions, including awareness building, training opportunities, and facilitating access to advanced technologies, is crucial for fostering greater resilience and ensuring the sustainability of agricultural production in the face of ongoing climate change.

Qualitative data obtained from focus group discussions and key informant interviews have revealed a complex landscape of adaptation strategies in the Gabiley region. Focus group discussions with smallholder farmers indicated that while some actively implement adaptation measures, their efforts are often constrained, including a reliance on traditional, sometimes outdated techniques and a low perceived efficacy of their current strategies, likely exacerbated by recurrent droughts. Agricultural experts from key informant interviews corroborated these farmers' perspectives, confirming the increasing frequency of droughts and flash floods. Furthermore, these experts noted that even when community-based programs and training promote practices such as water harvesting and sustainable land management, their overall effectiveness is significantly undermined by institutional challenges, primarily national plans perceived as ineffective and poorly coordinated, leading to delayed disaster responses. This identified disconnect between local adaptive efforts and broader institutional capacity emerges as a crucial barrier to building resilient agricultural communities in Gabiley.

3.5 Determinants of farmers' choices of adaptation strategies to climate change

The adaptive strategies of smallholder farmers in the face of climate change and variability were investigated using binary logit modelling. Binary logistic regression models were used to identify the determinants of the adoption of three key adaptation strategies: (i) adjusting the crop calendars, (ii) implementing water harvesting and irrigation techniques, and (iii) utilizing varied/drought-tolerant crop types. The models sought to elucidate the influence of farmers' socioeconomic characteristics and farm-related attributes on their likelihood of adopting these strategies. Parameter estimates derived from the regression analyses (reported in Table 6) were interpreted in conjunction with their corresponding significance levels (p-values) to assess the strength and direction of variable effects.

The results indicate a significant influence of education on the adoption of all three adaptation strategies. Specifically, education level positively impacted the likelihood of adjusting crop calendars ($\beta = 5.174$, $p = 0.020$), implementing water harvesting and irrigation ($\beta = 14.375$, $p = 0.000$), and utilizing drought-tolerant crops ($\beta = 10.952$, $p = 0.000$), suggesting that more educated farmers are more receptive to adapting their practices in

Table 6 Determinants of adaptation strategies to climate change. *Source*: *Field Data 2024*

Explanatory variable	Adjusting crop calendars			Water harvesting & irrigation			Drought-tolerant crops		
	Coef	SE	*P* > z	Coef	SE	*P* > z	Coef	SE	*P* > z
Gender	1.512	0.933	0.503	0.829	0.522	0.766	0.995	0.482	0.992
Age	0.973	0.026	0.304	0.99	0.022	0.658	0.960	0.019	**0.036**
Education	5.174	3.649	**0.020**	14.375	8.561	**0.000**	10.952	6.66	**0.000**
Households size	1.969	0.338	**0.000**	1.479	0.218	**0.008**	1.717	0.224	**0.000**
Employment	0.117	0.097	**0.010**	3.918	3.061	0.080	1.306	0.778	0.654
Livestock ownership	1.935	1.304	0.327	0.856	0.600	0.824	0.575	0.315	0.312
Access market	1.077	0.659	0.904	0.088	0.056	**0.000**	0.424	0.200	0.069
Awareness climate change	.144	0.172	0.105	0.157	0.194	0.133	1.438	1.458	0.720
Source info	2.325	0.665	**0.003**	1.422	0.389	0.198	1.046	0.224	0.832
Experience drought	3.096	2.666	0.189	51.55	69.998	**0.004**	8.025	6.525	**0.010**
Frequency climate events	1.104	0.32	0.733	1.963	0.613	**0.031**	2.266	.608	**0.002**
Rainfall pattern change	5.305	4.095	**0.031**	1.765	1.374	0.465	2.255	1.469	0.212
Rainfall onset	12.134	12.92	**0.019**	0.345	0.257	0.153	0.490	0.295	0.235
Rainfall cessation	9.795	7.181	**0.002**	2.520	1.614	0.149	5.824	3.409	**0.003**
Temperature pattern change	0.246	0.223	0.121	31.784	26.256	**0.000**	0.326	.199	0.066

The bold indicate statistical significance levels: *** and ** denote significance at the 1% and 5% probability levels, respectively

response to perceived climate risks. Household size also emerged as a consistent positive predictor across all models, demonstrating a statistically significant and positive relationship with the adoption of adjusted crop calendars (β = 1.969, p = 0.000), water harvesting and irrigation (β = 1.479, p = 0.008), and drought-tolerant crops (β = 1.717, p = 0.000). This finding implies that larger households, potentially possessing greater labor resources, are better positioned to implement necessary changes.

Beyond socioeconomic factors, climate-related experiences play a crucial role. Experiencing drought events was a significant predictor of adopting water harvesting and irrigation (β = 51.55, p = 0.004) and drought-tolerant crops (β = 8.025, p = 0.010), highlighting the importance of perceived risk in driving adaptive behavior. Similarly, the frequency of climatic events positively influenced the adoption of both water harvesting/irrigation (β = 1.963, p = 0.031) and drought-tolerant crops (β = 2.266, p = 0.002). Specific rainfall pattern changes also proved to be key motivators for adjusting crop calendars, with significant positive associations observed for rainfall pattern changes (β = 5.305, p = 0.031), onset (β = 12.134, p = 0.019), and cessation (β = 9.795, p = 0.002). Conversely, engagement in off-farm employment exhibited a negative association with adjusting crop calendars (β = 0.117, p = 0.010), suggesting potential constraints on time and labor availability for farmers engaged in external employment, potentially limiting their ability to respond proactively to changing weather conditions. Intriguingly, farmers with greater market access exhibited a negative association with the adoption of water harvesting and irrigation techniques (β = 0.088, p = 0.000). This may indicate that farmers with established market linkages prioritize alternative adaptation strategies, such as diversifying crops for market sale or investing in technologies that directly enhance market-oriented production, rather than focusing on water management. Finally, age was negatively associated with the adoption of drought-tolerant crops (β = 0.960, p = 0.036), implying that younger farmers are more likely to innovate and adopt novel cropping strategies, potentially because of greater risk tolerance, access to information, or a longer time horizon for realizing the benefits of climate-resilient practices.

In conclusion, the findings underscore the importance of both socioeconomic characteristics and prior experience with climate extremes in shaping farmers' adaptation decisions. Education, household size, and exposure to climate variability, particularly drought events and alterations in rainfall patterns, have emerged as critical determinants of adaptive capacity in smallholder farmers.

4 Discussion

This study reveals a complex interplay of sociodemographic and environmental factors influencing climate change adaptation among smallholder farmers in Somaliland's Gabiley Region. These findings underscore adaptation barriers and enablers, offering critical insights for policy and practice that resonate with broader empirical evidence from East Africa.

The predominance of older male farmers (over 49 years) highlights a demographic profile that potentially hinders innovative adaptation strategies. This aligns with studies from northern Uganda [6] and southern Ethiopia [24], attributing such resistance to entrenched traditional practices and risk aversion in older male-dominated farming communities. While larger household sizes (> six members) facilitate adaptation via labor pooling and resource sharing [16, 17], illiteracy, limited market access, and labor shortages remain formidable challenges. These results corroborate the broader literature, in which education and resource accessibility are pivotal for adaptive capacity in smallholder systems [5, 7].

Farmers in Gabiley have reported a stark rainfall decline and increased drought frequency over 30 years, mirroring Ethiopian trends [4, 8]. The resulting crop failures, soil degradation, and ecological decline have spurred localized adaptations such as adjusting planting calendars. However, the limited adoption of systemic strategies (e.g., crop diversification and soil conservation) underscores the need for institutional support, as seen in Ethiopia, where policy and extension services are critical for scaling adaptation [15, 33].

Education, household size, employment, and direct climate experience were identified as pivotal factors that shaped adaptation decisions. The positive correlation between education and the likelihood of adaptation echoes the findings of Gemeda et al. [16] and Asfaw et al. [5], reinforcing the role of knowledge in overcoming risk aversion. Similarly, the adaptive advantage of larger households aligns with labor-driven models [17], while employment significance reflects financial resources and information access [7]. Notably, drought exposure emerged as a powerful motivator for action, a pattern documented in studies linking climate shocks to behavioral change [33].

While a cross-sectional survey design limits causal inference, a mixed-methods approach strengthens the validity of the findings. Quantitative data reveals broad associations, while qualitative narratives contextualize these patterns, elucidating, for instance, how traditional norms mediate older farmers' resistance. Although purposive village selection restricts generalizability, it enables targeted exploration of diverse climate experiences, enriching the study's depth. This approach mirrors the work of Bewket [8] and Mekonnen et al. [24], balancing the scope and nuances of climate adaptation research.

These findings advocate multifaceted interventions: tailored education and extension to bridge knowledge gaps among older farmers; improved resource accessibility via market linkages, microfinance, and labor-saving technologies; and institutional support for climate information dissemination and tenure security [5, 7]. This study contributes to the smallholder adaptation literature by delineating Somaliland-specific barriers and enablers, demonstrating convergence with regional evidence on universal challenges, such as education and resource access, while underscoring the need for localized solutions. Future research should explore the longitudinal impact of adaptation interventions to further refine policies and practices.

5 Conclusion and recommendations

This study provides critical insights into climate variability and adaptation strategies employed by smallholder farmers in the Gabiley region of Somaliland. These findings underscore the substantial challenges posed by climate change, manifested primarily through declining rainfall, increased drought, and adverse impacts on agricultural productivity. The older, less literate farmer demographics present a barrier to adaptation. Key determinants include education, household size, employment, market access, and climate experience with pivotal education. A coordinated multi-actor approach is essential for building resilience. To translate these findings into action, targeted recommendations are crucial: the government prioritizes participatory climate adaptation education for farmers, especially older demographics, and invests in rural infrastructure/market information to improve market access. NGOs: Empower community-based adaptation initiatives through technical assistance, promotion of drought-resistant crops, and sustainable soil and water conservation. Facilitating access to microfinance. Donors: Support a robust climate monitoring system for early warnings and fund research on climate-smart agricultural practices for Gabiley. Concerning efforts from the government, NGOs, and donors are crucial. Decisive action is now needed to shift towards climate-resilient agriculture and secure the future for Gabiley farmers. Further research should rigorously evaluate intervention effectiveness, scale-up best practices, and explore innovative financing for long-term resilience.

Acknowledgements

The authors thank all respondents and agricultural experts at Somaliland's Ministry of Agriculture Development, with special thanks to Mustafe Ali and Eid Mohamed. Appreciation is also extended to Khadar Dahir for preparing the study area map. Furthermore, they express their gratitude to the University of Hargeisa for its partial support in conducting this study.

Author contributions

Mohamed Abdullahi Omer was responsible for the overall conception and design of the study as well as for data acquisition, analysis, and interpretation. He took primary responsibility for drafting the initial manuscript and integrating all the revisions requested during the peer review process. Saed Mohamoud Muhumed contributed significantly to the study's design, data analysis, and interpretation, and participated in the drafting of the manuscript. Asma Jama Mohamed contributed to the data analysis. Mossa Endris Ahmed contributed to the review and critical revision of the manuscript for important intellectual content. All authors critically reviewed the manuscript, approved the final version for publication, and agreed to be accountable for all aspects of this work.

Funding

The University of Hargeisa has partially supported this work.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study received ethical clearance from the Research Ethics Review Committee of the University of Hargeisa (Ethical Clearance No. DRCS/67/07/2024) prior to the commencement of data collection. Furthermore, explicit verbal informed consent was obtained from each study participant prior to their inclusion. Rigorous measures were implemented to maintain the confidentiality of all data collected, ensuring the protection of participant privacy.

Consent to publish
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 21 March 2025 / Accepted: 30 June 2025
Published online: 03 October 2025

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