

Research

Resilient agriculture in semi-arid Zimbabwe: adaptation strategies and influencers among smallholder farmers

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Abstract

Despite extensive research on climate change impacts and adaptation strategies in Zimbabwe, their effectiveness from the perspective of smallholder farmers, particularly in the Gwayi catchment remains insufficiently understood. This study evaluated adaptation strategies in response to land use change and climate variability using a mixed-methods approach. Data were collected through a survey of 483 smallholder farmers, 10 focus group discussions (8–12 participants), and interviews with 25 key informants. Results show that despite farmers' awareness of improved practices, adaptation remains constrained by limited access to water, quality seeds, and technology (64%), financial constraints (46%), and knowledge gaps (19%). The most common adaptation strategies include soil water conservation (85%), drought-resistant crops (80%), early planting (55%), and diversification (49%), with soil water conservation and drought-tolerant crops being the most widely practiced and perceived as most effective. Regression analysis indicates that livestock ownership, participation in community climate-resilient programs, and recent drought experiences significantly ($p < 0.05$) influence both the choice and number of adaptation strategies adopted. These findings highlight the need for context-specific interventions to mitigate the impacts of climate and land use changes on food security. Strengthening resilience among smallholder farmers requires improved resource access, livestock support, community-based resilience programs, capacity building, financial aid, and enhanced drought preparedness. Implementing these measures will bolster adaptive capacity and promote sustainable agricultural practices in the face of climate uncertainty.

Keywords Climate variability · Food security · Gwayi catchment · Land use change · Resource constraints

1 Introduction

Climate variability and land-use change (LUC) present significant challenges to agricultural systems worldwide [1, 2]. These factors disrupt productivity globally by altering precipitation patterns, increasing drought frequency and severity, and intensifying floods and temperature rises. Such disruptions contribute to widespread land degradation, which undermines soil fertility and reduces the effectiveness of agricultural practices. As a result, the stability

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of global food supplies is increasingly jeopardized, with significant implications for food security and economic stability in many regions [2].

These challenges are particularly pronounced in sub-Saharan Africa including Zimbabwe, where smallholder farmers rely heavily on rain-fed agriculture and have limited resources to adapt to changing conditions [3–5]. The region's vulnerability to climate variability and land degradation exacerbates the negative impacts of these factors on agricultural productivity and food security. Rising temperatures, erratic rainfall, and increased frequency of extreme weather events further compound these challenges, adversely affecting crop yields and livestock productivity [6–8]. In response, a range of adaptation strategies have been developed and promoted to help farmers cope with these changes. The agricultural adaptation strategies include the adoption of drought-resistant crop varieties, improved irrigation practices, agroforestry, and soil conservation techniques [8]. These strategies aim to enhance the resilience of farming systems by improving water use efficiency, maintaining soil health, and diversifying income sources [9]. Additionally, the use of climate information services and early warning systems has been shown to support better decision-making and risk management among farmers [10].

Adaptation strategies are critical to building climate resilience in agricultural systems. These strategies encompass a range of approaches from adopting new agricultural practices and drought-resistant crops [11] to utilizing advanced technologies and improved water management techniques [12]. Effective adaptation can help mitigate the adverse effects of climate change and LUC, thereby ensuring sustainable agricultural productivity and livelihoods [8]. Research exploring farmers' perceptions of adaptation strategies underscores the importance of local knowledge and context-specific solutions [13, 14]. Farmers' willingness to adopt certain strategies is influenced by their perceptions of the effectiveness, cost, and ease of implementing these measures [8]. For instance, studies have shown that while some farmers readily adopt new crop varieties because of their perceived benefits, others may be hesitant due to concerns about seed availability or unfamiliarity with new crops [8, 15].

Understanding farmers' perceptions of the effectiveness of existing adaptation strategies is essential. A study conducted in Nyanga District, Zimbabwe, for example, highlighted the importance of incorporating farmer perceptions into adaptation efforts [16]. Farmers' insights and experiences provide valuable information regarding the practicality, benefits, and limitations of various strategies in real-world settings [8]. The factors influencing the adoption and effectiveness of adaptation strategies include access to resources, information, and institutional support [5, 17, 18]. Socioeconomic factors such as education, income, and land tenure also play a crucial role in determining how and to what extent farmers can implement adaptation measures [19]. Moreover, the effectiveness of these strategies often depends on their integration into broader agricultural and development policies [6, 8, 16]. This understanding can guide the development of more effective and context-specific adaptation measures, ensuring that they align with the needs and capacities of smallholder farmers [20, 21].

Despite extensive research on climate change impacts and adaptation strategies in sub-Saharan Africa, a significant gap remains in understanding how these strategies are perceived and their effectiveness from the perspective of smallholder farmers [8, 9], particularly in the Gwayi catchment in Zimbabwe. Additionally, to the best of our knowledge, no study to date has comprehensively assessed the effectiveness of adaptation strategies in response to the combined effects of land use change and climate variability. This study aims to fill these gaps by adopting a farmer-centric approach with the following objectives: (a) analyse the adaptation strategies employed by smallholder farmers in the Gwayi catchment; (b) assess the perceived effectiveness of these strategies from the farmers' perspective; (c) explore the challenges faced by farmers in implementing these strategies; and (d) evaluate how socioeconomic and institutional factors influence the adoption and effectiveness of these adaptation measures. The study's novelty lies in its comprehensive examination of adaptation strategies within the context of both land use change and climate variability, a combination not previously addressed in the Gwayi catchment or similar regions. By focusing on these specific contexts, of the Gwayi catchment, this research contributes to a deeper understanding of the efficacy of adaptation measures and provides insights that can inform the design of more responsive and sustainable agricultural interventions.

2 Methods

2.1 Study area description

The study was conducted within the Gwayi catchment, located in western Zimbabwe (centered between latitudes 17°S to 20°S and longitudes 26°E to 29°E), which covers a total area of approximately 94,858 km² (Fig. 1). The catchment spans

Matabeleland North Province and extends into parts of the Midlands Province, bounded to the west by Botswana and hydrologically linked to the Zambezi River basin to the north. Administratively and hydrologically, the catchment is divided into five sub-catchments: Lower Gwayi, Upper Gwayi, Shangani, Mbembesi, and Nata. Geologically, the Gwayi catchment lies on the Kalahari group sediments, a sequence of tertiary-to-recent unconsolidated sands and calcretes, underlain by Archean basement rocks (greenstone belts) and Proterozoic basaltic formations [22]. These geological units influence soil development, with dominant soils including Kalahari sands (coarse, well-drained sandy soils) and shallow, nutrient-poor clays derived from weathering of greenstone belts and basalts [23]. Greenstone belts in the region comprise metamorphosed volcanic and sedimentary rocks rich in iron and magnesium, while Proterozoic basalts contribute to clay-rich, vertic soils prone to cracking during dry periods.

The catchment falls within Zimbabwe's agroecological regions IV and V, characterized by low annual rainfall (450–600 mm), periodic droughts, and severe dry spells [24]. Temperature variations are significant, ranging from 5 °C (mean minimum) to 35 °C (mean maximum) [22]. The semi-arid climate, combined with low-fertility soils, limits agricultural productivity. Demographically, the catchment supports approximately 200,000 households, with a population density of 10 people/km². Subsistence agriculture dominates the rural socioeconomic landscape, primarily reliant on rain-fed cultivation of drought-tolerant crops like maize and sorghum [25]. Small-scale irrigation schemes provide limited resilience, though challenges persist due to soil infertility and climate variability.

2.2 Study design

This study employed a cross-sectional survey approach to gather data from 483 smallholder farmers residing in the Gwayi catchment, Zimbabwe. Household heads aged 18 and above male or female were studied and where the household head

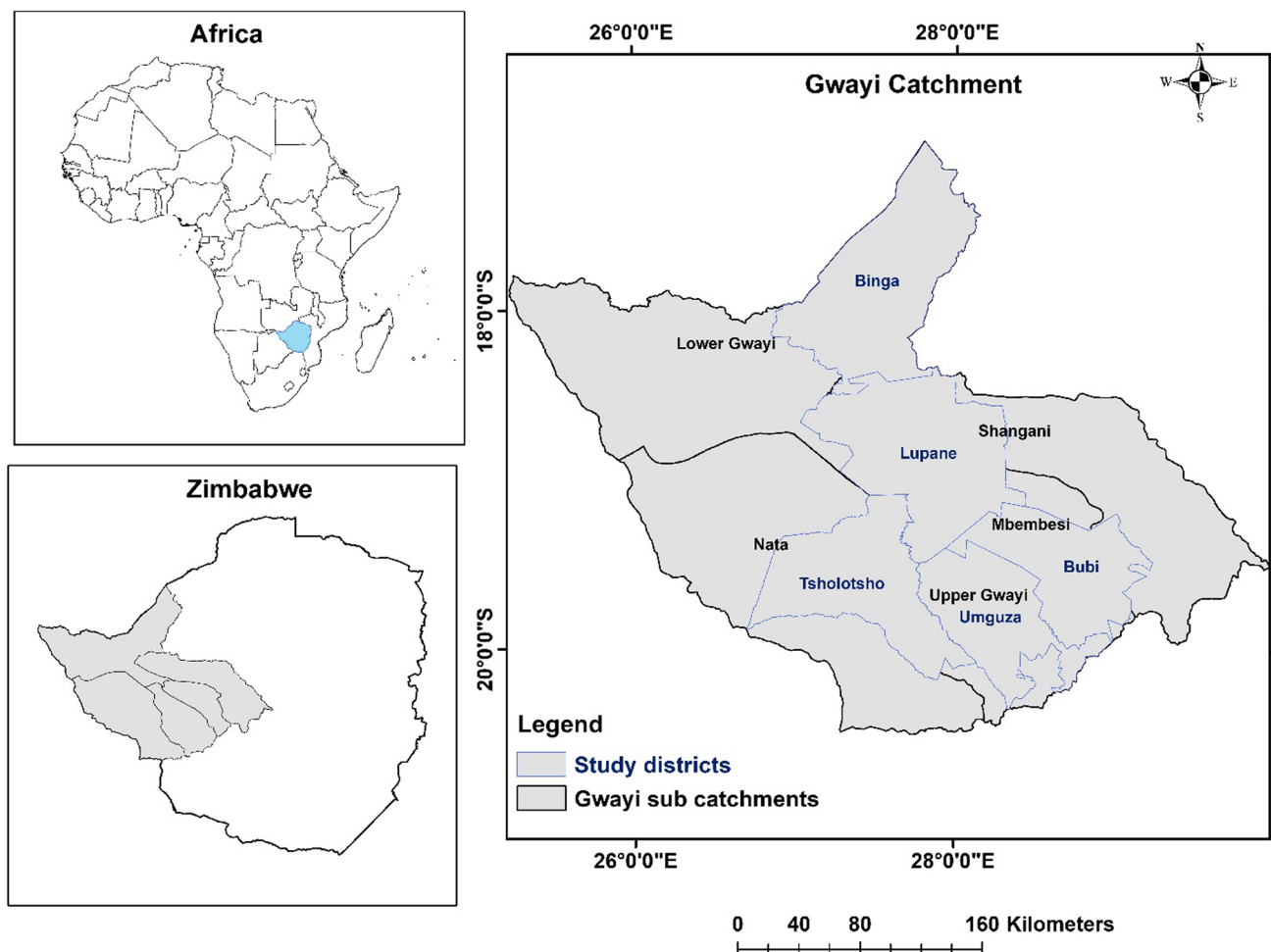


Fig. 1 Map of the Gwayi catchment of Zimbabwe (drawn by the authors)

was absent the next adult person in charge was interviewed. Out of the 483 completed household questionnaires, 199 were completed by females, accounting for approximately 41.2% of the sample, while 284 were completed by males, representing about 58.8%. The key informants included traditional leaders, extension personnel, and environmental officers.

2.3 Sampling

This study employed a combination of probability and non-probability sampling techniques within a multistage sampling approach to gather data from smallholder farmers in the Gwayi catchment of Zimbabwe (Fig. 2). The unit of analysis was the individual farm household. Initially, the catchment was stratified into five sub-catchments, from which one district was purposively selected to represent each sub-catchment's unique climate and vegetation characteristics (Table 1). Districts with dominant tourist or mining activities were excluded to ensure a focus on agricultural communities. Using population data from the 2022 Zimbabwe preliminary census report [26], a target sample size of 487 households was determined, aiming for approximately 97–98 respondents per district (Table 1). To minimize sampling error, [27] Eq. (1) was utilized to calculate the optimal number of wards and households per selected district, targeting a margin of error below 10% at the district level and 5% for the entire catchment. Within each selected ward, households were randomly selected. A pilot test involving 50 participants, with 10 respondents from each district in first and second week of March 2024, was conducted across the catchment. This sample size was chosen to represent the diverse farming communities. Feedback from these participants was crucial in refining the questionnaire to better align with the needs and conditions of the main study population [28]. Of the targeted 487 households, 483 completed the survey, resulting in a high response rate of 99.1%. The four non-responses occurred due to the total absence of household members during the

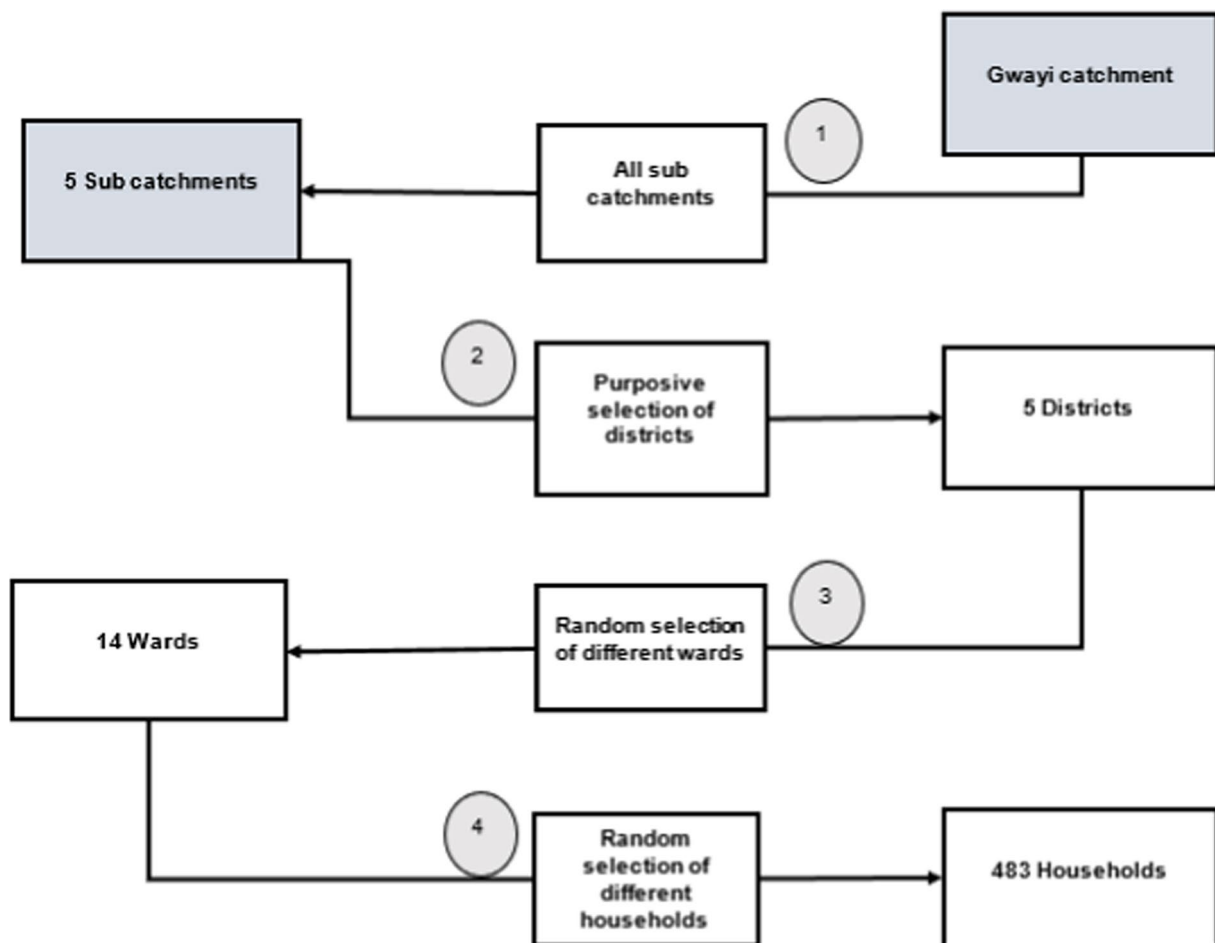


Fig. 2 Multi-stage Sampling approach

Table 1 Sample size for each district

Sub catchment	Selected district	Households (preliminary census report 2022)	Total number of wards	Calculated HH Sample		Completed HH questionnaires
				Wards	Households (HH)	
Nata	Tsholotsho	26,668	22	3	98	98
Shangani	Lupane	23,028	28	3	97	97
Upper Gwayi	Umguza	28,358	19	2	97	96
Mbembesi	Bubi	18,252	23	3	97	96
Lower Gwayi	Binga	39,495	25	3	98	96
Total		135 801	117	14	487	483

N.B:

survey period. Despite efforts to follow up, these attempts were unsuccessful due to the considerable distances between households in the rural areas, which made repeated visits impractical.

$$n = \frac{z_{\alpha/2}^2 \times N \times p(1-p)}{e^2 \times (N-1) + z_{\alpha/2}^2 \times p(1-p)} \quad (1)$$

where: n is the sample size; N is the population size; $z_{\alpha/2}$ is the critical value of the normal distribution at a confidence level of α ; e is the margin of error; p is the sample proportion, and $p(1-p) = \sigma^2$ represents the variance of the estimator.

2.4 Data collection

This study employed a cross-sectional survey approach to gather data from 483 smallholder farmers residing in the Gwayi catchment, Zimbabwe. A self-administered questionnaire, developed following guidelines of similar studies [28–30], to ensure clarity and comprehensiveness, served as the primary data collection tool. The questionnaire was structured to align with the study's objectives, focusing on key areas such as demographics, farmers' perceptions and land use and climate change adaptation strategies, and community-level initiatives related to land use and climate change adaptation. The survey combined closed-ended questions for efficient data collection with open-ended questions to capture in-depth insights from the farmers. A Likert scale was also utilized to assess the perceived effectiveness of various adaptation methods. To maintain confidentiality and anonymity, the questionnaire did not include personal identifiers. Data collection was authorized by the relevant extension department within the Gwayi catchment area. The quantitative data collected through the questionnaire was complemented by qualitative data collection methods, including key informant interviews and focus group discussions (FGDs). A total of 25 key informants (14 females and 11 males) comprising extension officers, traditional leaders, and environmental officers were interviewed, with five key informants selected from each of the five districts. Additionally, ten focus group discussions, comprising mixed groups of twelve participants each (both men and women), were conducted in the selected districts to capture diverse community viewpoints. The FGDs, each lasting approximately 60–70 min, were structured around the main study themes and designed to capture diverse viewpoints on land use change and climate change adaptation. The choice of group size for the FGDs (8 to 12 participants) followed commonly recommended practices to ensure a range of views while allowing every participant to contribute meaningfully to the discussion [30].

2.5 Data analysis

2.5.1 Quantitative data analysis

To analyse the survey data, we employed a combination of descriptive and econometric techniques. Descriptive statistics were calculated using STATA version 14 to provide a comprehensive overview of smallholder farmers' adaptation strategies, their perceptions of effectiveness, and the challenges they encountered. Before conducting the analysis, the data from Likert scale items underwent rigorous quality checks to ensure accuracy and reliability. These checks included handling missing data through appropriate imputation methods, identifying and addressing outliers, verifying internal consistency within the scales, and calculating inter-item correlations to assess the reliability of the scales used. These data quality checks helped to ensure that the subsequent analyses were based on high-quality, reliable data. For the econometric analysis, a multinomial logistic regression model was employed to delve deeper into the factors influencing the choice of specific adaptation strategies (Eq. 2) in R version 4. This model was chosen because, as highlighted by [31], this model offers an advantage over options, such as binary logit, by enabling the analysis of decisions across multiple categories (e.g., various adaptation strategies) and the calculation of choice probabilities for each category, which aligns with our objective to understand the diversity of adaptation choices among farmers. The dependent variables included five prominent drought adaptation strategies: drought-resistant varieties, water-harvesting techniques, soil and water conservation, early sowing, and diversification of crops and livestock. The independent variables consisted primarily of demographic characteristics, land use changes, and participation in community resilience programs. Additionally, Poisson regression analysis (Eq. 3) was conducted to examine how various factors influenced the total number of adaptation strategies adopted by each farming household. This method was selected due to its suitability for modelling count data, allowing us to assess the relationship between the independent variables and the number of strategies employed by respondents, which is crucial for understanding the extent of adaptation efforts. Table 2 presents a description of the explanatory variables hypothesized to influence farmers' selection of effective adaptation strategies. It outlines the variables included in the multinomial logistic regression analysis, their measurement indices, and the expected relationship or prior expectation concerning the adaptation strategies in the final column.

$$P(y = j|X) = \frac{e^{\beta_j' X}}{1 + \sum \left(e^{(\beta_k' X)} \right)} \quad (2)$$

where: $P(y = j|X)$ represents the probability of a farmer choosing adaptation strategy j given a set of independent variables X ; β_j is a vector of coefficients specific to adaptation strategy j . There will be one β_j vector for each of the five dependent variables (drought-resistant varieties, water harvesting, etc.); X is a vector representing the independent variables: (i) Age; (ii) Gender; (iii) Livestock ownership; (iv) Marital status; (v) Number of household members; (vi) Education; (vii) Digital extension access; (viii) Income; (ix) Years of farming experience; (x) Drought experience; (xi) Community-based resilience program participation; (xii) Land-use changes; and $\sum(\exp(\beta_k' X))$ represents the sum of the exponentiated terms for all possible categories (k) of the dependent variable. This term acts as the denominator in the function, ensuring that the probabilities for all categories sum to 1.

$$E(y|X) = e^{(\beta' X)} \quad (3)$$

where: $E(y|X)$ represents the expected number of adaptation strategies adopted by a farmer given a set of independent variables X ; β is a vector of coefficients estimated by the model. There will be one coefficient for each independent variable; X is the same vector representing the independent variables listed in the multinomial logistic regression (refer to the previous list of variables on equation 2).

2.5.2 Qualitative data analysis

Qualitative data from interviews and focus group discussions were analysed using thematic analysis. This involved a systematic process of identifying, coding, and categorizing key themes and patterns within the data. Themes were classified based on a combination of the research objectives and emergent patterns observed in the data. By carefully examining

Table 2 Description of variables for multi-nominal regression analysis

Variable	Type	Measurement	Expected effect on the dependent variable	References
i. Age	Continuous	Years	May have a positive or negative effect depending on experience and adaptability	[9, 19]
ii. Gender	Categorical	1 = Male, 2 = Female	May affect access to resources and decision-making, potentially influencing resilience	[31]
iii. Livestock ownership	Categorical	1 = Yes, 0 = No	Positively influences resilience by providing income and assets during droughts	[32]
iv. Marital Status	Categorical	1 = Married, 0 = Not Married	May affect household decision-making and resource allocation, influencing resilience	[33]
v. Number of household members	Continuous	Number	Larger households may have more labor but also higher consumption needs, mixed effect on resilience	[31]
vi. Education	Categorical	1 = Formal education, 0 = None	Generally positive effect, as education improves access to information and adaptation strategies	[9, 31]
vii. Digital extension access	Categorical	1 = Yes, 0 = No	Positive effect by improving access to timely information and modern farming techniques	[7, 21]
viii. Income	Continuous	Amount in local currency	Positive effect, as higher income provides better access to resources and adaptation options	[21]
ix. Years of farming experience	Continuous	Years	Positive effect, as experience can lead to better adaptation strategies and decision-making	[19, 21]
x. Drought experience	Categorical	1 = Yes, 0 = No	Positive or negative effect depending on the capacity to learn from past experiences	[34]
xi. Community-based resilience program participation	Categorical	1 = Yes, 0 = No	Positive effect by enhancing knowledge, skills, and access to collective resources	[21, 31]
xii. Land-use changes	Categorical	1 = Yes, 0 = No	Can have mixed effects, depending on whether changes lead to degradation or sustainable practices	-

the responses, we identified recurring themes related to farmers' perceptions of climate change, their experiences with adaptation strategies, the factors influencing their decisions, and the challenges they encountered. This approach ensured that the themes directly addressed the research questions and provided a structured framework for analysing the data. During the analysis, qualitative data were used to generate insights by comparing and contrasting responses across different interviews and focus group discussions. Thematic coding allowed for the identification of recurring patterns and key issues, which were then grouped into thematic categories. This process involved iterative review and refinement of codes and categories to ensure that the themes accurately represented the data. By examining the data through a thematic lens, this study aimed to provide a rich and nuanced understanding of the complex issues surrounding climate change adaptation among smallholder farmers in the Gwayi catchment.

3 Results

3.1 Farmer demographics and characteristics

The demographic profile of the smallholder farmers, shown in Tables 3 and 4, provides valuable insights. The average age was 50 years (standard deviation: 13.17), ranging from 18 to 87 years, reflecting a mix of traditional knowledge and openness to new methods. Household sizes averaged 5.81 members (range: 1–13), with smaller households potentially facing labour constraints and limited access to modern farming technologies. Larger households may have greater capacity for agricultural activities and information access. The landholding size was consistently 3.5 hectares, which is the standard landholding size for all smallholder farmers in the study area. Therefore, it was not considered an influencing variable, since it was uniform across all participating households. The farming experience averaged 19.82 years, indicating a substantial depth of agricultural knowledge among respondents. Family income averaged \$166.09 per month, with a wide range from \$0.8 to \$1400, indicating varying economic capacities among the households. Despite limited access to formal education, with a majority possessing only primary or secondary qualifications, farmers exhibited a reasonable level of digital technology adoption, with over half owning smartphones and utilizing platforms like WhatsApp and SMS for information access. While platforms like Instagram and Twitter were not used, their inclusion highlights the limited reach and preference for simpler platforms among the respondents. However, irrigation practices remained largely limited, with the vast majority of farmers relying on rainfall. These demographic characteristics provide a foundation for understanding the context within which farmers operate and inform the analysis of adaptation strategies. These demographic characteristics provide a crucial foundation for understanding the context within which farmers operate. They inform the analysis of adaptation strategies by highlighting key factors such as age, household size, experience, income, and access to technology, which collectively influence the farmers' capacity to adapt.

3.2 Types of adaptation strategies

3.2.1 Individual farmer adaptation strategies

Farmers in the Gwayi region use multiple strategies to manage climate risks (Table 5). Soil water conservation practices were most common (85%), followed by drought-resistant crops (80%), early sowing (55%), and crop and live-stock diversification (49%). A small percentage of farmers (7%) reported that they did not use specific adaptation strategies. A Chi-square test revealed significant variations in adaptation strategies across districts ($p = 2.42e-92$, $df = 260$), indicating a highly significant difference in practices ($p < 0.05$). The Binga district had the highest adoption rate for drought-resistant crops (91%), while Umguza had the lowest (71%). Water harvesting techniques were most

Table 3 Background and demographics of the respondents ($n = 483$) (Survey Data, 2024)

Variables	Mean	Std. Dev.	Min	Max
Age (years)	49.52	13.17	18	87
Number of household members	5.81	2.00	1	13
Number of years of farming experience	19.82	12.40	1	68
Family income	166.09	187.82	0.8	1400
Number of emigrations	1.07	1.35	0	8

Table 4 Description of demographic variables of the respondents (n = 483) (Survey Data, 2024)

Variables	Percentage (%)
Gender of the household head	
Male	58.80
Female	41.20
Marital status	
Married	68.74
Other (single, divorced, separated, windowed)	31.26
Education	
Primary incomplete	14
Primary	27
Secondary incomplete	23
Secondary	30
A level	1
Tertiary	4
No education	1
Type of phone owned	
Smartphone	57
Non -smartphone	34
No phone	10
Social media applications used for extension information	
WhatsApp	55
Facebook	7
Instagram	0
Twitter	0
SMS	48
Other	19
Type of irrigation used	
Flood	14.49
Drip irrigation	2.07
None	83.44

Table 5 Land use and climate change adaptation strategies by district (Survey Data, 2024)

Strategies	% response					Overall %
	Binga	Bubi	Lupane	Tsholotsho	Umguza	
Drought resistant crops	74	91	84	78	71	80
Water harvesting techniques	1	77	47	56	3	38
Soil water conservation strategies	82	97	77	84	89	85
Early sowing	48	82	58	50	39	55
Diversification of crops and livestock	29	84	52	59	22	49
No specific practices	4	27	2	0	1	7

prevalent in Binga (77%) and least prevalent in Umguza (3%). Soil water conservation practices are widely used across all districts (ranging from 77 to 97%). Early sowing was most common in Binga (82%) and least common in Tsholotsho (39%). In terms of diversification strategies, Binga had the highest adoption rate (84%), and Umguza had the lowest adoption (22%). Additionally, a majority of the farmers (87.58%) adapted to specific crops or varieties in response to changing climatic conditions. Moreover, the survey revealed that smallholder farmers in Gwayi are embracing technology to adapt to climate change. They primarily use weather forecast apps, social media platforms such as WhatsApp groups, and traditional methods such as observing nature to obtain daily updates and predict weather patterns. Although less common, some farmers utilize advanced tools such as soil moisture sensors for irrigation management. This integration of modern and traditional approaches empowers them to make informed decisions

regarding planting, irrigation, and crop protection, ultimately building resilience and ensuring sustainable agriculture in the face of a changing climate.

3.2.2 Community awareness and programs on adaptation strategies

The survey results indicate that 54.66% of respondents are aware of the various adaptation strategies used within their communities. Further analysis of the survey data revealed that 21% of these respondents reported learning about these strategies through direct interactions with other farmers, demonstrating the presence of farmer-to-farmer information exchange. However, there is a notable gap in the awareness of official community-based resilience-building programs, with only 50.52% of farmers acknowledging these initiatives. Findings from the survey also show that 86.34% of farmers have recently adopted new agricultural practices aimed specifically at addressing climate change. This highlights the proactive nature of the community in embracing innovative techniques to enhance resilience. The practices include modern approaches such as conservation agriculture, climate-smart agriculture, and water-harvesting techniques. These practices are complemented by the use of plastic mulching to retain soil moisture and responsible livestock management to prevent land degradation. The interviews and survey also identified a diverse range of adaptation strategies employed by Gwayi farmers. They encompass both modern and traditional knowledge systems. Modern approaches emphasize sustainable land management through conservation agriculture, such as Zimbabwe's Pfumvudza farming technique. They also include climate-smart agriculture to enhance resilience and water-harvesting methods like infiltration pits and boreholes to secure water during dry periods. Plastic mulching is used to retain soil moisture and suppress weeds, whereas responsible livestock management through destocking practices prevents land degradation. Some farmers in the region actively integrate technology into their practices, utilizing weather forecast applications, social media platforms, and SMS services to access timely weather updates and inform decision-making. However, the adoption of these technologies remains uneven, as factors such as socioeconomic status and network availability influence farmers' access and ability to utilize them effectively. Qualitative findings revealed that farmers in Gwayi complement their agricultural practices with traditional knowledge systems. For instance, observations of natural indicators such as tree formations and bird behaviour are incorporated into decision-making processes. This synergistic use of modern innovations and indigenous wisdom positions farmers to enhance their resilience in the face of evolving climate challenges.

3.2.2.1 Community-based programs The results from key informant interviews and focus groups reveal that community-led strategies for building climate resilience in the Gwayi catchment are multifaceted. Five key strategies emerged based on their frequency of mention: (1) knowledge-sharing platforms (45 mentions), (2) joint resource management initiatives (38 mentions), (3) conservation agriculture practices (52 mentions), (4) seed and livestock programs (29 mentions), and (5) disaster risk reduction and resilience-building programs (33 mentions). Conservation agriculture practices and knowledge-sharing platforms were the most frequently cited. Respondents highlighted the role of WhatsApp groups, farmer field schools, and workshops in disseminating climate-smart practices and supporting conservation agriculture. These platforms are seen as essential for facilitating the exchange of experiences and adaptation to changing climatic conditions. Joint resource management initiatives also feature prominently, with community seed banks, grazing land management, and shared irrigation schemes being regularly mentioned. These initiatives often involve collaborations between farmers, local organizations, (Non-Governmental Organisations (NGOs), and Agricultural Technical and Extension Services (AGRITEX). The analysis further identifies conservation agriculture practices, such as urea stover treatment and silage making, as significant for enhancing land productivity and sustainability. Seed and livestock programs, including community seed banks and goat production groups, are noted for their role in bolstering the community's resilience. Additionally, disaster risk reduction and resilience-building programs, like workshop training and solar-powered irrigation, are reported to help mitigate the effects of climate-related disasters. The involvement of the private sector and NGOs, through NGO-sponsored projects and private sector contributions to grazing land management, is recognized as a vital complement to community efforts, fostering a comprehensive approach to climate resilience that integrates traditional practices with modern techniques and external support.

3.3 Farmer perceptions of the effectiveness of adaptation methods

Farmers' evaluations of the effectiveness of adaptation strategies vary. Drought-resistant crops were deemed very effective by 59.43% of the farmers and extremely effective by 6.2% (Table 6). Water harvesting techniques were considered very effective by 41.76% and extremely effective by 23.08% (Table 5). Soil water conservation strategies

Table 6 Effectiveness of the adaptation strategies by district (Survey data, 2024)

Strategies	% response				
	(Not effective)	(Somewhat effective)	(Moderately effective)	(Very effective)	(Extremely effective)
Drought resistant crops	0	4.39	29.97	59.43	6.2
Water harvesting techniques	1.65	3.3	30.22	41.76	23.08
Soil water conservation strategies	0.24	5.83	35.44	44.9	13.59
Early sowing	1.49	10.82	58.96	26.12	2.61
Diversification of crops and livestock	2.09	10.88	44.35	32.22	10.46
No specific practices	84.38	3.13	6.25	0	6.25

were rated as very effective by 44.9% of farmers and extremely effective by 13.59%. Early sowing was considered moderately effective by 58.96% of respondents and very effective by 26.12%. The diversification of crops and livestock was deemed moderately effective by 44.35% and very effective by 32.22%. In contrast, the absence of specific practices was largely seen as ineffective by 84.38% of the farmers.

Table 7 Multinomial logistic regression results for multiple dependent variables (Survey Data, 2024)

Independent variable	Dependent variable				
	Drought resistant varieties ¹	Water harvesting techniques ²	Soil and water conservation ³	Early sowing ⁴	Diversifying crop and livestock ⁵
Age	-0.031* (0.016)	-0.013 (0.015)	-0.001 (0.018)	-0.018 (0.014)	-0.023 (0.014)
Gender	-0.339 (0.285)	-0.018 (0.252)	0.344 (0.322)	0.053 (0.249)	0.406 (0.249)
Livestock ownership	0.636* (0.266)	1.470*** (0.257)	0.212 (0.295)	1.110*** (0.234)	1.450*** (0.241)
Marital Status	-0.004 (0.308)	-0.564* (0.276)	-0.508 (0.364)	-0.466 (0.273)	-0.716** (0.275)
Number of household members	0.069 (0.071)	-0.068 (0.062)	-0.008 (0.080)	-0.036 (0.061)	-0.086 (0.060)
Education	0.119 (0.125)	0.313** (0.114)	-0.174 (0.142)	0.140 (0.110)	0.193 (0.109)
Digital extension	-0.140 (0.286)	-0.0004 (0.254)	0.572 (0.328)	-0.503* (0.254)	-0.203 (0.250)
Income	-0.0005 (0.001)	0.001 (0.001)	0.002* (0.001)	0.004*** (0.001)	0.002** (0.001)
Years of farming experience	0.047** (0.016)	0.026 (0.015)	0.002 (0.018)	0.020 (0.014)	0.033* (0.014)
Drought experience	-0.138 (0.173)	0.178 (0.154)	0.162 (0.197)	0.555*** (0.161)	0.502** (0.156)
Community based resilience programs	0.311 (0.254)	1.190*** (0.229)	0.846** (0.293)	1.260*** (0.230)	0.896*** (0.222)
Land use changes	0.199 (0.112)	-0.248* (0.098)	0.255* (0.129)	0.065 (0.096)	0.159 (0.095)

*p < 0.05; **p < 0.01; ***p < 0.001

The figures in parentheses represent the standard errors of the coefficients

Akaike Inf. Crit (AIC) AIC¹=468.000, AIC²=552.000, AIC³=391.000, AIC⁴=559.000, AIC⁵=570.000

3.4 Factors influencing the choice of adaptation strategies

An analysis of the relationships between various influencing factors and the different adaptation strategies chosen by smallholder farmers is presented in Table 7. Owning livestock, especially cattle and donkeys, was a significant factor in most adaptation strategies (drought-resistant varieties, water harvesting techniques, early sowing, diversifying crops, and livestock). This suggests a potential correlation between livestock ownership and the adoption of integrated crop-livestock systems, which could enhance resilience to drought. Participation in community-based resilience programs was positively associated with the adoption of all five adaptation strategies, highlighting the effectiveness of such programs in promoting drought preparedness. Recent drought experiences were associated with an increased likelihood of farmers choosing early sowing and diversification practices as adaptation methods. Farmers who have faced droughts before may be more motivated to implement preventive measures. There was a weak negative association between age and the adoption of drought-resistant varieties, suggesting that younger farmers are more open to new technologies.

Table 8 shows the results of the Poisson regression analysis, in which the dependent variable is the number of strategies adopted by farmers. The analysis examined how various factors (independent variables) influence the number of adaptation strategies used. A positive coefficient (0.261) suggests that farmers participating in community-based resilience programs are more likely to adopt strategies (a higher expected number). The effect size was also significant ($p = 0.0000032$). A positive coefficient (0.334) indicates that farmers with livestock are more likely to adopt strategies than those without livestock. This effect was statistically significant ($p = 0.0000001$). Although the coefficient (0.00036) was positive, it was very small. It might not have a practically significant effect on its own, but it suggests a possible trend in which higher income might be linked to adopting more strategies. The p-value (0.0088) suggested a statistically significant effect, but further investigation is needed to understand its practical impact. Similar to income, the coefficient (0.0079) was small but positive. More years of experience might be linked to the adoption of more strategies, but the effect size might be minimal. A p-value of 0.0278 indicated statistical significance. The positive coefficient (0.0767) suggests that farmers who have experienced drought are more likely to adopt strategies. This effect was statistically significant ($P = 0.0392$) of the other factors significantly influence the number of strategies adopted. Overall, this analysis suggests that factors such as community programmes, livestock ownership, income (potentially), farming experience (potentially), and drought experience play a role in the adoption of adaptation strategies. Participation in community programs and livestock seems to have the strongest positive influences.

Table 8 Factors influencing the number of strategies adopted by smallholder farmers (Derived from Survey Data, 2024)

Independent variable	Coefficients	Estimate Std. Error	z value	Pr(> z)
Age	- 0.0056809	0.0036985	- 1.536	0.12454
Gender	0.0290501	0.0625868	0.464	0.64254
Marital Status	- 0.1313281	0.0668618	- 1.964	0.04951*
Number of household members	- 0.0093140	0.0152481	- 0.611	0.54131
Education	0.0349943	0.0270669	1.293	0.19605
Digital Extension	- 0.0235116	0.0630575	- 0.373	0.70925
Income	0.0003606	0.0001378	2.617	0.00888**
Years of farming experience	0.0078850	0.0035829	2.201	0.02775*
Drought experience	0.0767389	0.0372105	2.062	0.03918*
Community based resilience	0.2610172	0.0560156	4.660	3.17e-06***
Livestock ownership	0.3336219	0.0631648	5.282	1.28e-07***
Land use changes	0.0221637	0.0236817	0.936	0.34933

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(The dispersion parameter for the Poisson family is taken to be 1.)

Null deviance: 398.22 for 471 degrees of freedom

Residual deviance: 307.75 on 459 degrees of freedom

(11 observations deleted due to missing data)

AIC: 1685.5

Number of Fisher scoring iterations: 4

3.5 Challenges in implementing adaptation strategies and critical areas of extension intervention

Limited access to resources (64%) emerged as the most significant challenge faced by farmers when adopting adaptation strategies (Table 1). This was followed by financial (46%), lack of knowledge or training (19%), and time constraints (28%). A small percentage of respondents mentioned other challenges. These findings highlight the resource limitations faced by smallholder farmers in the Gwayi Region. Implementing some strategies, such as water-harvesting techniques, may require financial investment in equipment or materials. The acquisition of drought-resistant seeds can be hindered by financial constraints. A lack of knowledge or training on effective adaptation practices and time pressures associated with farm management further restricts the adoption of strategies. Farmers emphasized the need for local leaders and extension services to provide training and technical advice (61.08%), facilitate community collaboration (35.20%), and provide funding (3.73%). These findings highlight critical areas where support and interventions are needed to enhance the resilience of smallholder farmers in the Gwayi catchment to climate change and variability.

4 Discussion

This study examines adaptation strategies among smallholder farmers in Zimbabwe's Gwayi catchment to address climate variability and land-use change. Findings reveal a proactive approach, with many farmers adopting soil and water conservation practices, drought-resistant crops, and early sowing. The use of drought-resistant crops, particularly sorghum and millet, underscores this proactive approach, as these crops mature faster and offer better resilience to pests and diseases. Similar observations were documented in research conducted by [31], where farmers' adoption of drought-tolerant crops was linked to improved yields and food security. This aligns with findings from studies in comparable semi-arid regions of East and Southern Africa, including Ethiopia, Kenya, Botswana, Namibia, and parts of South Africa, where smallholder farmers have implemented similar climate variability management strategies [6, 19, 31, 35].

While variations in adoption rates exist across districts, the overall trend indicates a growing awareness and implementation of effective adaptation strategies. For instance, Binga district, identified as highly vulnerable to drought and food insecurity by [36] shows higher adoption rates for drought-resistant crops and water harvesting compared to Umguza. This disparity is likely due to targeted support for conservation farming in Binga and the influence of Umguza district's proximity to Bulawayo, which affects crop preferences and practice adoption. Geographic factors, such as rainfall patterns and soil types, influence the perceived effectiveness of strategies like the Pfumvudza conservation farming program [37]. Additionally, socioeconomic factors, including access to resources and extension services, also play a role in the adoption of these practices [38, 39]. Despite these variations, the widespread adoption of soil and water conservation practices across districts suggests their perceived effectiveness and relative ease of implementation.

While 54.66% of respondents in Gwayi are aware of adaptation strategies, there remains significant potential to enhance outreach and education. This aligns with findings from Ethiopia [31] and Kenya [40], which underscore the importance of farmer-to-farmer communication for spreading climate-smart practices. Farmers in the Gwayi catchment are demonstrating the effectiveness of combining traditional ecological knowledge with modern tools. This is evident in their use of WhatsApp groups and weather applications to adapt to changing weather patterns. This integration of indigenous knowledge systems and scientific advancements is crucial for building climate resilience. However, it is important to acknowledge that occasional tensions can arise between local practices and religious beliefs. Fortunately, in the case of Gwayi catchment farmers, the majority viewed their traditions and religious beliefs as complementary rather than contradictory. Expanding such adaptive frameworks to other regions could promote a more holistic and inclusive approach to resilience building. This finding aligns with the notion that blending indigenous and scientific knowledge can be a powerful tool for climate adaptation efforts [41].

Our study found that smallholder farmers in the Gwayi catchment predominantly raise small stock and poultry, which are widely recognized for their adaptability to drought conditions due to their lower feed and water requirements [42]. Livestock diversification plays a crucial role in building resilience in drought-prone areas [42], however, destocking, particularly for cattle, remains a key survival strategy during severe droughts [43]. Findings from our

research confirm that farmers in Gwayi frequently resort to destocking cattle while prioritizing small stock, such as goats and poultry, which require fewer resources and demonstrate greater resilience to drought conditions. This strategy reflects a balance between the need for livestock diversification and the practical challenges of managing larger livestock during periods of resource scarcity. While respondents reported diversification into smaller livestock as moderately to very effective, they continue to face difficulties in sustaining larger livestock like cattle during prolonged dry periods, often making destocking a necessary adaptation. These findings align with existing knowledge on livestock management strategies in drought-affected regions.

The study also highlights the role of government, NGO, and community-led programs in supporting adaptation efforts. Government initiatives, such as AGRITEX extension services and infrastructure development, provide essential inputs and improve water access. NGOs contribute by promoting conservation agriculture, establishing community seed banks, and implementing disaster risk reduction measures. Community-led initiatives, including knowledge-sharing platforms and collective actions, underscore the importance of local collaboration and traditional practices in building resilience. These platforms, as noted by the findings of [44], are vital for disseminating climate-smart practices and fostering peer learning. Research also indicates that farmer-centred participatory approaches within communities enhance adaptive capacity and promote sustainable resource management [41, 45, 46]. The adoption of climate-smart techniques, such as Pfumvudza and other conservation agricultural practices, aligns with global efforts toward sustainable agricultural practices. These methods, documented by [47, 48] and [49], not only improve yields but also enhance soil health and water retention, which are crucial for building long-term resilience.

This study provides valuable insights into farmers' perceptions of the effectiveness of adaptation strategies. Respondents consistently rated drought-resistant crops and soil conservation as highly effective, which aligns with findings from other studies [35, 50, 51]. These strategies were seen as improving crop yields, reducing water loss, and enhancing soil fertility, thus contributing to overall agricultural resilience. In contrast, water harvesting, despite positive evaluations, has lower adoption rates. This discrepancy likely reflects cost and labour constraints, highlighting the need for targeted interventions to address these barriers.

The study also identifies factors influencing the choice of adaptation methods. Livestock ownership, involvement in community programs, and recent drought experiences were positively associated with the adoption of multiple strategies. This finding is consistent with research in Ethiopia [31] and South Africa [21], which found a positive correlation between livestock ownership and the adoption of drought-resistant crops. Livestock owners often have a stronger incentive to adopt such crops as they benefit both human and animal feed, enhancing the resilience of their farming systems. Furthermore, the study suggests a potential correlation between younger aged farmers and a higher likelihood of adopting drought-resistant crops, indicated by a weak negative association between age and adoption rates. This aligns with research in Malaysia [52, 53], which suggests that younger farmers may be more receptive to agricultural innovations due to factors such as higher education levels, greater exposure to new technologies, and a propensity for risk-taking.

Despite farmers' proactive efforts to adapt to changing climatic conditions, widespread implementation of effective strategies is hindered by significant resource and financial constraints. The high cost of agricultural inputs, such as improved seeds, fertilizers, and irrigation equipment, coupled with limited access to credit and savings, severely restricts farmers' ability to invest in these essential resources. Moreover, the reliance on rain-fed agriculture in many regions exacerbates the challenges associated with resource scarcity, as farmers often lack the financial means to invest in supplementary irrigation systems. Addressing these constraints is vital for ensuring the sustainability of the adaptation strategies deployed in the Gwayi catchment, especially given the increasing climate pressures on agriculture. These findings echo similar challenges reported in studies across sub-Saharan Africa [54, 55]. The emphasis placed by farmers on the need for training and technical advice aligned with the identified knowledge gap. Additionally, fostering community collaboration and providing access to funding were crucial areas for intervention. Extension services can play a vital role by providing targeted training programs, facilitating access to credit and resources, and fostering linkages with relevant stakeholders [54].

5 Limitations of the study

While this study provides valuable insights, several limitations must be acknowledged. The reliance on self-reported data through surveys may introduce biases, as respondents' perceptions and recall may not fully represent their actual experiences. However, the study also utilized multiple data collection tools, including Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs), which helped triangulate the findings and mitigate some of these biases. Despite this,

the cross-sectional design restricts the ability to capture the evolving nature of adaptation strategies over time. Therefore, while the qualitative data collected through KIs and FGDs contributed to a more comprehensive understanding, the interpretation of the results should still be approached with these limitations in mind. Future research should aim to address these gaps, potentially by incorporating longitudinal studies and employing an even broader range of data collection methods to build upon the findings of this study.

6 Conclusion and recommendations

This study set out to understand the adaptive capacity of smallholder farmers in Zimbabwe's Gwayi catchment, where escalating climate impacts such as erratic rainfall and land degradation pose increasing threats to livelihoods. The research aimed to assess farmers' adaptation strategies and identify the systemic barriers limiting their resilience. Key findings indicate that farmers are adopting low-cost, accessible strategies, particularly soil and water conservation (85%) and drought-resistant crops (80%). However, widespread implementation of these practices is constrained by systemic inequalities, including limited water access (64%), financial constraints (46%), and knowledge gaps (19%). Adaptive capacity was found to be strongly influenced by factors such as livestock ownership, participation in community-led initiatives, and previous drought experiences. Younger farmers, in particular, demonstrated a greater openness to integrating indigenous knowledge with digital tools like weather apps. These insights underscore the urgent need for targeted, equity-focused interventions. Policies must prioritize improved access to drought-tolerant seeds, microfinance, and inclusive platforms for climate information exchange. The effectiveness of community-driven initiatives such as shared irrigation systems and seed banks highlights the transformative potential of localized solutions. However, disparities in access to resources must be addressed to ensure that these benefits are equitably shared. This study offers a framework for designing context-sensitive, adaptive policies that can strengthen climate resilience in Gwayi and other similarly vulnerable semi-arid regions. While the mixed-methods approach provided valuable insights, reliance on self-reported data and a cross-sectional design limits the ability to assess long-term adaptation outcomes. Future research should prioritize longitudinal studies to track adaptive changes over time, investigate generational knowledge transfer, and evaluate the scalability of public-private partnerships. Comparative studies across agroecological zones will also be critical to understanding adaptation in diverse contexts. Additionally, exploring the role of digital technologies in enabling knowledge sharing and adaptive action presents a promising avenue for further investigation. Ultimately, building resilience in the Gwayi catchment requires a holistic, inclusive approach—one that bridges resource gaps, fosters innovation, and combines indigenous knowledge with modern tools.

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Data availability The data and materials supporting the results presented in this paper are available from the first author, Bright Chisadza, upon reasonable request.

Declarations

Research involving human participants and/or animals Informed consent was obtained from all study participants, ensuring they were thoroughly briefed on the research objectives and their rights as participants. Furthermore, ethical approval for conducting interviews with farmers and extension personnel was granted by the Medical Research Council of Zimbabwe (Approval Number: MRCZ/A/3234), in accordance with their ethical guidelines and protocols.

Competing interests The authors declare no competing interests.

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