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Adaptive household strategies for sustaining crop production under conditions of water scarcity in semi-arid South Africa

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Water scarcity is emerging as one of the most pressing constraints to smallholder crop production in semi-arid regions, threatening the very basis of rural livelihoods that rely heavily on rainfed agriculture. In this context, small household gardens stand out as resilient spaces of food production, often more reliable and manageable than larger croplands exposed to climatic stress. This study explores how households in a semi-arid communal area of South Africa mobilize strategies to sustain crop production in gardens amid condition of persistent water scarcity. A mixed-methods approach was employed, incorporating a structured survey of 192 households and focus group discussions. Quantitative data were analyzed using chi-square tests, while qualitative data were thematically coded to capture local narratives. The results show that 63.1% of households are female-headed, with women more likely than men to experience crop failure due to water scarcity (53.3% vs. 27.2%). Education emerged as a significant factor ($p < 0.05$), with higher attainment associated with reduced vulnerability to water stress. While irrigation was widely practiced (78%), adoption of water-saving practices remained modest and skewed toward households with basic education and grant-based income. A clear distinction was observed between *indigenous practices* such as manuring and rainwater harvesting, commonly applied at the household level, and formal Climate-Smart Agriculture strategies, of which awareness and adoption remained low. The findings highlight compounded vulnerabilities among aging, female-led, low-income households and underscore the necessity for targeted, education-sensitive interventions to strengthen resilience in semi-arid food systems.

KEYWORDS

water scarcity, smallholder food gardens, climate-smart agriculture, irrigation practices, household vulnerability

1 Introduction

Water scarcity presents an escalating threat to smallholder crop production in semi-arid regions (Pamla et al., 2021; Karimi et al., 2024), where rural livelihoods are deeply tied to local agricultural systems (Rapholo and Diko, 2020; Msweli et al., 2025). Semi-arid areas in southern Africa, including much of South Africa, typically receive only 400–650 mm of rainfall annually and are prone to high inter-annual variability and frequent droughts (Bonetti et al., 2022; Onyeuwaoma et al., 2024). Climate change is intensifying water

scarcity, where erratic rainfall patterns, recurrent droughts (Mahlalela et al., 2020; Dzvene et al., 2022; Muchaku, 2024) and declining soil moisture are becoming more frequent, crop production systems are increasingly vulnerable (Dzvene et al., 2025a; Gebrechorkos et al., 2025). Vulnerability undermines water availability for farming communities presenting a dual challenge: to maintain agricultural productivity under conditions of persistent water stress (Oyeagu and Lewu, 2025), while ensuring long-term sustainability and food security (Biswas et al., 2025). Within this context, household crop production, particularly through small gardens, emerges as a vital, adaptable buffer for food availability, offering greater security and manageability than larger, field-level croplands (Carstens et al., 2021; Dawid et al., 2023; Gush et al., 2024).

Smallholder farmers, who form the backbone of rural food systems in South Africa (Madhavan and Schatz, 2007; Zenda et al., 2024), have historically relied on rain-fed agriculture and traditional knowledge to navigate climatic variability (Baffour-Ata et al., 2023; Zenda, 2024). They are disproportionately exposed due to limited access to irrigation infrastructure and institutional neglect (Thabane et al., 2025; Matimolane and Mathivha, 2025). However, the intensifying severity and frequency of droughts have begun to exceed the coping range of conventional practices, exposing the fragility of existing farming systems. Studies in the Eastern Cape have highlighted how droughts exacerbate food insecurity, poverty, and rural migration, revealing the socio-economic pressures faced by these households (Adom et al., 2023; Mdoda et al., 2024; Tanto and McKay, 2023). In response, rural communities are adopting diverse strategies, ranging from low-tech water-saving methods (e.g., mulching, gray-water use) to cultivating drought-tolerant crops such as maize, beans, pumpkins, and leafy vegetables, alongside the integration of indigenous agroecological practices (Qadir et al., 2010; Altieri and Nicholls, 2020; Fantoso and Yessoufou, 2022; Mapuka et al., 2024; Mgxaji et al., 2025). Although farmers utilize both traditional and modern approaches, their adaptive capacity remains constrained by inadequate policy support, resource access, and limited awareness of climate-smart practices.

Despite growing conceptual understanding of resilience and adaptive strategies at regional scales, there remains a critical lack of empirical insights into household-level adaptation strategies in South African communal semi-arid zones. Previous studies (e.g., Adom et al., 2023; Mdoda et al., 2024) have documented localized responses, yet there is little systematic evidence on how households sustain crop production under chronic water scarcity, especially in communal settings where institutional support is weak. Moreover, while Climate-Smart Agriculture has been widely promoted as a policy framework for climate adaptation (Mudzielwana et al., 2025), few studies have examined how its principles are understood, interpreted, or integrated at the household level in semi-arid South Africa. This disjuncture between top-down Climate-Smart Agriculture frameworks and grassroots practices represents a critical research gap, particularly in communal areas where indigenous strategies dominate but remain under-recognized (Mwongera et al., 2017). Addressing this gap is vital not only for strengthening climate-resilient livelihoods but also for informing context-specific

policy frameworks and adaptation programmes in water-scarce agroecological zones.

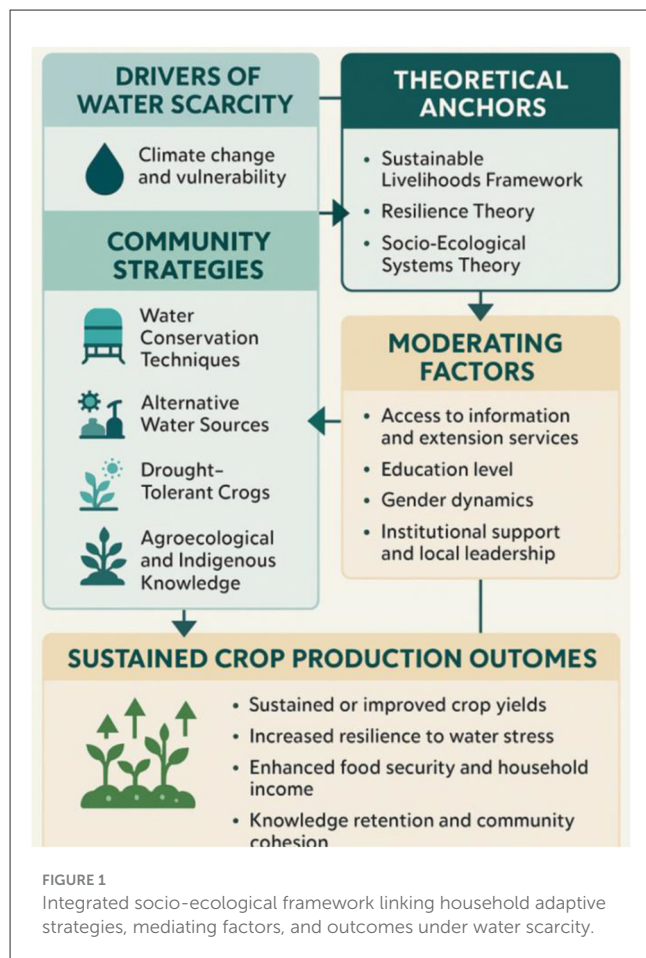
This study responds to this gap by documenting household-level strategies for sustaining crop production under water scarcity in semi-arid South Africa. Using a mixed-methods approach, the study develops an integrated socio-ecological conceptual framework that draws on the Sustainable Livelihoods Framework (DFID, 1999), Resilience Theory (Folke et al., 2002), and Socio-Ecological Systems (SES) thinking (Ostrom, 2009). By explicitly linking empirical evidence with theoretical perspectives, the framework highlights the dynamic interplay between environmental stressors, community responses, and institutional enablers. In doing so, it provides a grounded basis for assessing agricultural resilience and guiding targeted interventions aimed at sustainable food production under climate stress.

2 Conceptual framework

This study applies an integrated socio-ecological framework to direct the investigation and interpretation of household strategies for sustaining crop production amid water scarcity in semi-arid South Africa. The framework is empirically grounded in the data obtained from this study and judiciously incorporates established theoretical traditions to enhance our comprehension of community responses, rather than functioning as an independent theoretical model. The framework combines three perspectives: the Sustainable Livelihoods Framework (SLF) (DFID, 1999), which emphasizes the role of livelihood capitals (human, natural, social, financial, and institutional) in shaping adaptive choices; Resilience Theory (Folke et al., 2002), which highlights the ability of agroecosystems to absorb shocks and maintain core functions; and Socio-Ecological Systems (SES) thinking (Ostrom, 2009), which prioritizes the interactions among ecological stressors, human decisions, and governance contexts.

At its core (Figure 1), the framework conceptualizes water scarcity as a compound stressor, driven by climatic variability, recurrent droughts, soil degradation, and weak water governance (Middleton, 2011; Kusangaya et al., 2014). These pressures directly influence water availability, agricultural viability, and household food security. The framework recognizes that households respond to these pressures through a suite of adaptive strategies, such as irrigation, mulching, gray-water use, planting drought-tolerant crops (maize, beans, pumpkins, leafy vegetables), and implementing indigenous agroecological practices (Msweli et al., 2025).

These strategies are not adopted in a vacuum. Their success is conditioned by mediating factors such as gender dynamics, educational attainment, income sources, and access to extension services and weather information (Altieri and Nicholls, 2020; Nhamo et al., 2019). For example, our data show that women-headed households reported higher rates of crop failure, while households with higher educational attainment were more likely to adopt water-saving practices. In line with SLF, these differences reflect disparities in access to livelihood capitals and institutional support. Resilience Theory is particularly useful for interpreting these findings, as it draws attention to how households balance



immediate coping needs with longer-term system sustainability. SES thinking adds further nuance by situating household decisions within broader feedback loops between ecological stressors (e.g., declining rainfall), institutional enablers (e.g., extension services, markets), and cultural norms that shape adaptation practices. The framework therefore links stressors → mediating factors → adaptive strategies → outcomes, with outcomes feeding back into future strategy formation. In this study, outcomes are operationalised through indicators such as yield stability, reduced vulnerability, and improved household food security. By embedding empirical insights within a multi-theoretical structure, the framework provides both an interpretive tool and a practical basis for designing targeted interventions that enhance resilience in semi-arid food systems.

3 Materials and methods

3.1 Study area

The study was conducted in the Raymond Mhlaba Local Municipality (RMLM), located in the Eastern Cape Province of South Africa (Figure 2). The Eastern Cape is the country's second-largest province, covering approximately 169,000 km², 13.9% of South Africa's total land area. It lies between KwaZulu-Natal and the Western Cape, with the Indian Ocean forming its southern and eastern boundary. The province includes two metropolitan

municipalities (Nelson Mandela Bay and Buffalo City), six district municipalities, and 37 local municipalities. Raymond Mhlaba forms part of the Amathole District Municipality and is situated at approximately 32.2968° S and 26.4194° E. The municipality is predominantly rural, with small towns such as Fort Beaufort, Alice, and Middledrift, which serve as administrative and service hubs.

The area experiences a semi-arid to sub-humid climate, characterized by variable rainfall patterns ranging between 400 mm and 800 mm annually, often marked by prolonged dry spells and erratic seasonal distribution. Water sources include municipal boreholes, rivers, seasonal streams, and limited rainwater harvesting systems. The local economy is driven largely by subsistence agriculture, small-scale livestock farming, and social grants, with high levels of unemployment and poverty. Many households rely on food gardening to supplement their nutrition and income. However, these gardens are vulnerable to water scarcity due to poor infrastructure, drought-prone conditions, and limited institutional support. These contextual challenges make RMLM an appropriate site for exploring how communities manage and sustain household gardens under water stress.

3.2 Human ethics and consent to participate declarations

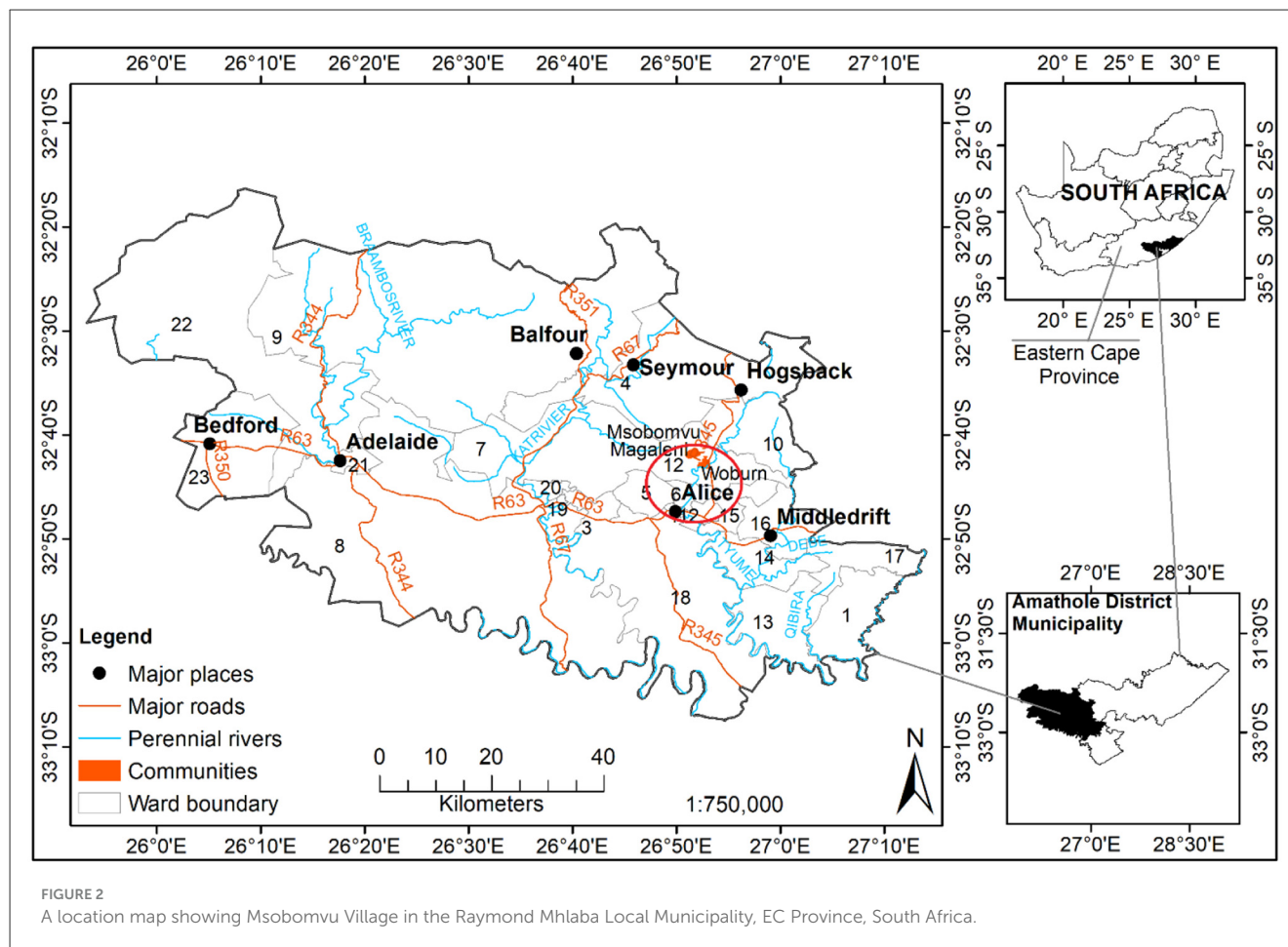
This study received ethical approval from the University of Fort Hare Research Ethics Committee (Ethics Clearance Reference Number: ZHO001-24). All procedures involving human participants adhered to the ethical standards of the institution and complied with national guidelines for research involving human subjects. Informed consent was obtained from all participants prior to their involvement in the study. Participants were fully informed about the study's purpose, procedures, risks, and benefits. Confidentiality and anonymity were maintained throughout data collection, analysis, and reporting. No personal identifiers were used, and participation was entirely voluntary, with the option to withdraw at any stage without consequence.

3.3 Research design and data collection

To explore household-level experiences of water scarcity, local adaptation strategies, and perceptions of water use in home gardening, this study adopted a mixed-methods approach integrating quantitative and qualitative data. The research was conducted in Msobomvu village, situated within the Raymond Mhlaba Local Municipality in South Africa's Eastern Cape Province, a region increasingly vulnerable to water insecurity due to climate variability.

The target population consisted of approximately 540 households engaged in home gardening, as estimated from village registers and verified by community leaders. A sample size of 192 households was calculated using Yamane's formula (1967) at a 95% confidence level and a 5% margin of error, ensuring representativeness of the findings (Yamane, 1967).

A two-stage sampling procedure was employed. Household registers from local authorities served as the primary sampling frame, while systematic random sampling (every third household



along pedestrian pathways) was used where registers were incomplete. Only households actively involved in food gardening were included.

Quantitative data were collected using a structured questionnaire administered through face-to-face interviews in participants' native languages by trained local enumerators. The instrument was pretested in a neighboring community with similar socio-environmental conditions to ensure clarity, contextual appropriateness, and reliability.

To complement survey findings, four focus group discussions (FGDs) were conducted with purposively selected participants, stratified by gender, age group, and gardening experience. Recruitment was facilitated by community leaders and expanded through snowball sampling to identify experienced gardeners. Each FGD comprised 8–10 participants, yielding a total of 36 discussants.

The FGDs explored perceptions of water scarcity, inter-household water-sharing practices, barriers to conservation, and community-based adaptation practices. Data collection took place in April 2024, with qualitative sampling ceasing once data saturation was reached. All interviews and discussions were audio-recorded with consent, transcribed, and translated for thematic analysis.

3.4 Statistical thematic content analysis

Quantitative data were analyzed using IBM SPSS Statistics Version 29 (SPSS Inc., Chicago, IL, USA). The analysis comprised two stages: (i) univariate analysis to describe socio-demographic characteristics and key variables related to household gardening and water use, including frequencies, percentages, and summary statistics; and (ii) bivariate analysis using Pearson's chi-square test (χ^2) to assess associations between socio-demographic variables, water scarcity experiences, and awareness of climate-smart practices. It is acknowledged that chi-square analysis identifies associations but does not establish causal relationships; results are therefore interpreted within this limitation. A significance level of $p < 0.05$ was used to indicate statistical significance. Qualitative data from open-ended survey responses and FGDs were analyzed thematically. Coding was conducted inductively to identify recurring patterns, perceptions, and strategies related to water management, constraints, and adaptive practices. Thematic analysis allowed for the integration of diverse community perspectives, complementing quantitative findings and strengthening the interpretation of results.

TABLE 1 Profiles of respondents and failure of gardening due to water scarcity in the Raymond Mhlaba local municipality.

Variable	Category	%	Experienced crop failure due to water scarcity?		Chi-square statistics
			Yes	No	
Sex	Male	36.9	27.2	9.7	0.063*
	Female	63.1	53.3	9.7	
Age	21–35 years	7.7	7.7	0	0.186 ^{ns}
	36–50 years	20.5	16.9	3.6	
	51–65 years	45.1	34.4	10.8	
	66+ years	26.7	21.5	5.1	
Marital status	Married	33.3	27.2	6.2	0.151 ^{ns}
	Single	45.1	38.5	6.7	
	Widowed	20.5	14.4	6.2	
	Divorced	1	0.5	0.5	
Household size	1–3 people	32.8	25.6	7.2	0.758 ^{ns}
	4–7 people	55.4	45.6	9.7	
	8–11 people	11.8	9.2	2.6	
Educational level	None	4.6	3.1	1.5	0.000**
	Primary	35.4	23.1	12.3	
	Secondary	54.9	49.2	5.6	
	Tertiary	5.1	5.1	0	
Income source	Grants	51.28	41.0	10.3	0.424 ^{ns}
	Informal trade	21.54	19.0	2.6	
	Formal job	12.31	9.7	2.6	
	Pension	14.9	10.8	4.1	
Garden use	Subsistence	64.1	47.7	16.4	0.015**
	Income generation	14.87	13.3	1.5	
	Occasional use	21.03	19.5	1.5	

*, ** significant at $p < 0.1$; 0.01; ns, non-significant.

4 Results

4.1 Household characteristics and water scarcity in crop cultivation

Table 1 summarizes the characteristics of the 192 surveyed households. A majority were female-headed (63.1%). Crop failure due to water scarcity was more frequently reported by female-headed households (53.3%) than male-headed households (27.2%), with this association bordering on statistical significance ($\chi^2 = 0.063$, $p < 0.1$). Respondents were predominantly older: 45.1% were aged 51–65, and 26.7% were 66 and above. Only 7.7% were aged 21–35, raising concerns about an aging farming population. However, no significant association was found between age and crop failure ($p > 0.05$). Education showed a strong association: households with higher education levels were less likely to experience crop failure ($\chi^2 = 0.000$, $p < 0.01$). Garden use was also important, subsistence gardens (64.1% of households) were more vulnerable to water stress than gardens used for income generation or occasional use ($\chi^2 = 0.015$, $p < 0.05$). Other variables (marital status, household size, and

income source) were not significantly associated with crop failure, though descriptive patterns suggest slightly higher crop loss among single and widowed households.

“We plant mainly to eat at home, but when there is no water, the whole garden dies, and we have nothing” (FGD1, female participant, April 2024, Msobomvu village).

This reflects the acute vulnerability of subsistence users whose household food security is directly threatened by crop failure. Another participant emphasized the psychological toll:

“When the garden fails, it feels like the whole family fails, we depend on it not just for food, but also for dignity” (FGD2, male participant, April 2024, Msobomvu village).

A younger participant expressed frustration about recurring challenges and their impact on youth involvement in farming:

“Young people like me lose interest in gardening because every season the rains fail, and we cannot afford tanks or pumps” (FGD3, youth participant, April 2024, Msobomvu village).

These quotations highlight how household characteristics intersect with gender, age, and resource access to shape vulnerability to water scarcity.

TABLE 2 Associations of household characteristics and garden water management in the Raymond Mhlaba local municipality.

Variable	Category	Irrigate your garden?			Adopt water-saving practices?		
		Yes	No	Chi-square statistics	Yes	No	Chi-square statistics
Sex	Female	75.6	24.4	0.425 ^{ns}	59.3	40.7	0.889 ^{ns}
	Male	80.6	19.4		58.3	41.7	
Age	21–35 years	66.7	33.3	0.193 ^{ns}	40	60	0.349 ^{ns}
	36–50 years	70	30		55	45	
	51–65 years	77.3	22.7		63.6	36.4	
	66+ years	86.5	13.5		59.6	40.4	
Marital status	Married	78.5	21.5	0.198 ^{ns}	60	40	0.435 ^{ns}
	Single	71.6	28.4		54.5	45.5	
	Widowed	87.5	12.5		65	35	
	Divorced	100	0		100	0	
Household size	1–3 people	79.7	20.3	0.846 ^{ns}	57.8	42.2	0.546 ^{ns}
	4–7 people	75.9	24.1		57.4	42.6	
	8–11 people	78.3	21.7		69.6	30.4	
Educational level	None	66.7	33.3	0.124 ^{ns}	44.4	55.6	0.076*
	Primary	87	13		71	29	
	Secondary	72.9	27.1		52.3	47.7	
	Tertiary	70	30		60	40	
Income source	Grants	45.6	5.6	0.000**	34.9	16.4	0.052*
	Informal trade	13.3	8.2		11.3	10.3	
	Formal job	7.2	5.1		5.1	7.2	
	Pension	11.3	3.6		7.7	7.2	
Garden use	Subsistence	49.7	14.4	0.311 ^{ns}	37.4	26.7	0.958 ^{ns}
	Income generation	12.8	2.1		8.7	6.2	
	Occasional use	14.9	6.2		12.8	8.2	

*, ** significant at $p < 0.1$; 0.01; ns, non-significant.

4.2 Factors influencing household food garden irrigation application

Table 2 presents the relationships between household characteristics and the application of irrigation and water-saving practices in household food gardens within Raymond Mhlaba Local Municipality. Overall, irrigation was widely practiced among respondents, with no statistically significant difference between male-headed (80.6%) and female-headed (75.6%) households ($\chi^2 = 0.425$, $p > 0.05$). Older household heads, particularly those aged 66 and above, had the highest irrigation application rate (86.5%), while the youngest group (21–35 years) reported the lowest (66.7%). However, differences across age groups were not statistically significant ($p > 0.05$). Marital status also showed no significant association with irrigation application, although widowed (87.5%) and divorced (100%) individuals appeared more likely to irrigate their gardens than their married or single counterparts. Similarly, household size was not a significant factor, although slightly higher irrigation rates were observed among larger households (1–3 people: 79.7%; 8–11 people: 78.3%).

Education level, while not statistically significant for irrigation application ($p = 0.124$), showed interesting trends. Respondents with primary education were most likely to irrigate (87%), followed by those with secondary (72.9%) and tertiary education (70%). Those with no formal education had the lowest irrigation rates (66.7%). Regarding the adoption of water-saving practices, there was no significant gender difference (females: 59.3%; males: 58.3%, $p = 0.889$). Older respondents, especially those aged 51–65 years, had the highest adoption rate (63.6%), while those aged 21–35 had the lowest (40%). Again, these differences were not statistically significant. Although not statistically significant, larger households (8–11 members) were more likely to adopt water-saving practices (69.6%), possibly reflecting greater awareness or need due to higher domestic water demand (Figure 3). Respondents with primary education again had the highest adoption of water-saving techniques (71%), compared to 44.4% among those with no education. This difference approached significance ($\chi^2 = 0.076$, $p < 0.1$), suggesting education may influence sustainable water management behavior. Income source showed statistically significant differences in both irrigation (χ^2



FIGURE 3
Photographs depicting home gardens and community water collection points in Msobomvu village.

$= 0.000$, $p < 0.01$) and water-saving practices ($\chi^2 = 0.052$, $p < 0.1$). Households relying on social grants were more likely to irrigate (45.6%) and adopt water-saving strategies (34.9%), followed by those engaged in informal trade and pension-based incomes. No significant association was observed between garden use purpose (subsistence, income generation, or occasional use) and either irrigation or water-saving behavior ($p > 0.05$), though subsistence users accounted for most irrigation and conservation adoption.

4.3 Household awareness of climate-smart agriculture (CSA) and adaptation strategies

Most households are unaware of the concept climate-smart agriculture (CSA) (Figure 4A). This is followed by those who have heard of the CSA concept, while a smaller number have training or are implementing CSA. The various water sources used for household garden irrigation shows that the majority rely on

municipal water (36%), followed by borehole water (30%) and rainwater harvesting (23%) (Figure 4B).

The association between household-level adaptation strategies and CSA awareness in Raymond Mhlaba Local Municipality reveals that (Table 3), among the strategies assessed, only the use of manuring exhibited a statistically significant relationship with CSA awareness ($\chi^2 = 0.066$; $p < 0.1$). Notably, a higher proportion of households unaware of CSA practices engaged in manuring (17.4%) compared to those with CSA awareness (2.1%), suggesting that this traditional practice may be more prevalent among households with limited exposure to CSA principles. Other strategies, including mulching, composting, intercropping, the use of drought-tolerant plants, and water conservation techniques, showed no significant association with CSA awareness.

4.4 Perceptions to water scarcity

Table 4 shows the water sources and associated challenges related to the sustainability of home food gardens in the Raymond Mhlaba Local Municipality. Responses from community

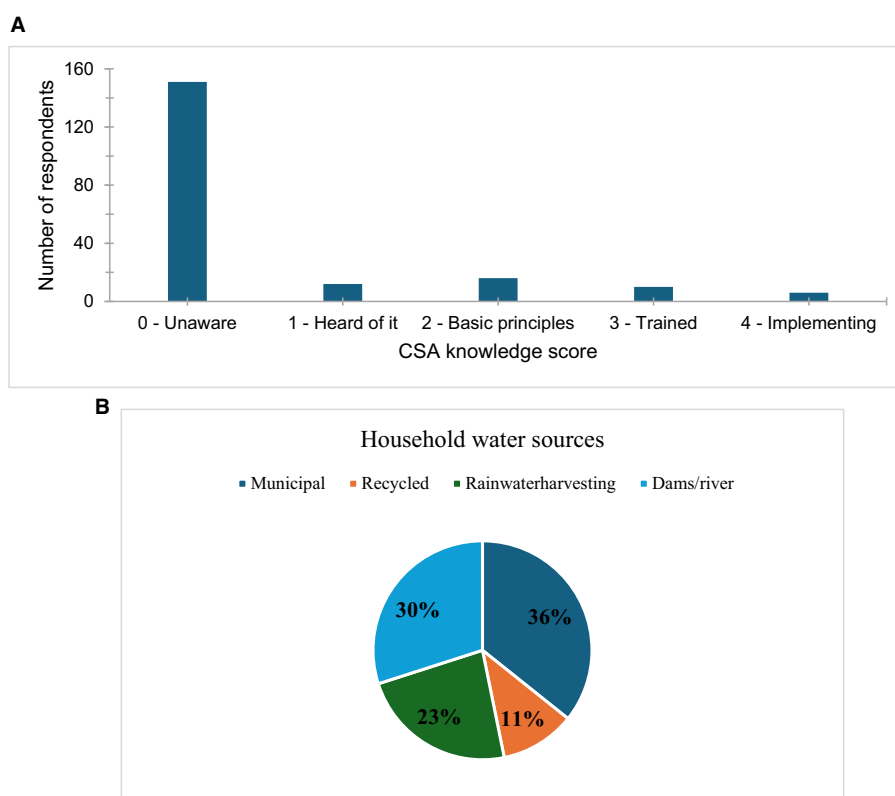


FIGURE 4

(A) CSA knowledge score and (B) water sources for garden irrigation in the Raymond Mhlaba local municipality.

members indicated that municipal water (36%) is the primary source and is more suitable for human consumption than other sources. Although there is some variability, community members are expected to have a consistent supply throughout the year, regardless of seasonal changes. Participants also reported that many communities are now connected to municipal water systems and use this water for gardening purposes. Another perspective that emerged from participants' responses is that dam or river water accounts for 30% of the water sources, likely because many communities, especially in rural areas, rely on rivers and dams as their primary water sources, creating a sense of familiarity and dependence on these resources. Utilizing natural water bodies such as dams or lakes can significantly reduce the cost of water for irrigation.

Community narratives emphasized both reliability and accessibility challenges:

"When the municipal taps run dry, we fetch from the river. Rainwater tanks help, but they are small and run empty very fast" (FGD2, female participant, April 2024, Msobomvu village).

"Sometimes we wake up at 3 a.m. to queue for water when the supply comes back. It is not enough for drinking, let alone for our gardens" (FGD1, male participant, April 2024, Msobomvu village).

"We know rainwater harvesting can save us, but without proper tanks, we are stuck using buckets, and it's not sustainable" (FGD3, youth participant, April 2024, Msobomvu village).

These quotations illustrate the multiple stressors that households face, not only physical scarcity but also infrastructural

limitations and resource inequities, that constrain the sustainability of gardening practices.

One of the benefits of rainwater harvesting (23%), as mentioned by respondents in this study, is that it provides communities with the opportunity to save water, particularly in regions facing water scarcity. This practice promotes self-sufficiency and reduces dependence on municipal water systems, which can be unreliable. The community members' preferences also showed a lower inclination toward recycled water (11%), possibly due to concerns about water quality and safety. Despite treatment processes, some gardeners may worry about potential contamination, while others may lack knowledge and awareness about water recycling. Other sources, such as boreholes and wells, were not utilized in the study, possibly due to the costs of installation. These water preferences indicate a complex relationship among reliability, accessibility, cost, and environmental considerations. Municipal water was the primary source, likely due to its recognized reliability and safety, while there is a strong interest in sustainable practices such as rainwater harvesting.

4.5 Crop production challenges

Responses from the participants indicated that weather conditions (38%), such as drought and heavy rains, are the main challenges for gardeners, as these conditions can destroy their crops. Another challenge identified by participants was

TABLE 3 Associations between household adaptation strategies and CSA awareness in the Raymond Mhlaba local municipality.

Variable	Category	%	CSA awareness		Chi-square statistics
			Yes	No	
Mulching	Yes	10.8	3.6	7.2	0.164 ^{ns}
	No	89.2	17.9	71.3	
Composting	Yes	6.7	0.5	6.2	0.209 ^{ns}
	No	92.31	21.0	72.3	
Manuring	Yes	19.5	2.1	17.4	0.066 ^{**}
	No	80.5	19.5	61.0	
Micro-basin tillage	Yes	9.2	2.6	6.7	0.499 ^{ns}
	No	90.8	19	71.8	
Intercropping	Yes	8.2	3.1	5.1	0.105 ^{ns}
	No	91.8	18.5	73.3	
Drought tolerant plants	Yes	7.2	2.6	4.6	0.180 ^{ns}
	No	92.8	19.0	73.8	
Use of watering cans	Yes	3.6	0.5	3.1	0.635 ^{ns}
	No	96.4	21.0	75.4	
Watering early or late in the day	Yes	13.3	10.8	2.6	0.758 ^{ns}
	No	86.7	19.0	67.7	
Storing water in plastic bottles	Yes	18.5	3.1	15.4	0.431 ^{ns}
	No	81.5	18.5	63.1	

*, ** significant at $p < 0.1$; 0.01; ns, non-significant.

harvest and crop production (24%), which was affected by various factors, including soil quality and crop selection, contributing to decreased yields. Knowledge and resource gaps (12%) also posed challenges for home food gardens. Some participants noted that a lack of community knowledge acted as a barrier, as they lacked information on food garden maintenance. Additionally, the availability of water (10%) emerged as a barrier affecting gardens in several ways, such as altering plant growth and changing growing and harvest seasons. Limited access to reliable water sources impacts plant growth and modifies growing seasons. Participants indicated that this challenge is particularly pronounced during dry spells, when reliance on alternative water sources becomes critical. Gardeners also struggle to find effective and environmentally friendly critter control methods. Furthermore, many participants expressed that the community lacked time and labor for their gardens due to long working hours.

5 Discussion

This study highlights the multidimensional nature of water scarcity and its impacts on smallholder households in the Raymond Mhlaba Local Municipality. Consistent with earlier work (Karimi et al., 2024; Rapholo and Diko, 2020), results confirm that water scarcity undermines rural livelihoods in semi-arid South Africa (Hove and Osunkunle, 2020; Pamla et al., 2021), with subsistence-focused households particularly vulnerable (Mnisi, 2020). The

TABLE 4 Water sources and associated challenges on the sustainability of home food garden in the Raymond Mhlaba local municipality.

S/N	Preference (%)	Challenges	Proportion (%)
Municipal water	36	Weather conditions	38
Dam/river water	30	Water availability	10
Rainwater harvesting	23	Pest and diseases	8
Recycled water	11	Knowledge and resource gap	12
Borehole	-	Critter Damage	2
Wells	-	Harvest and crop production	24
Lakes	-	Financial and space constrain	4
Spring	-	Time and labor	2
Total	100		100

association between garden use and crop failure underscores how households most reliant on gardening for food security face heightened risks (Adom et al., 2023; Tantoh and McKay, 2023).

Gendered disparities in vulnerability also emerged. Female-headed households were more often associated with crop losses, reflecting restricted access to land, water infrastructure, credit, and extension services (Dzvene et al., 2025b; Doss et al., 2018; Nhamo et al., 2019). As one participant explained during a focus group in Msobomvu (April 2024, FGD2): “We plant mainly to eat at home, but when there is no water, the whole garden dies, and we have nothing.” These challenges are compounded by cultural and institutional norms that exclude women from agricultural decision-making (Gonda, 2019). Limited access to information and training further reduces women’s ability to adopt water-saving technologies (Jost et al., 2016; Fantoso and Yessoufou, 2022). In contrast, male-headed households were more likely to diversify production and invest in coping strategies such as rainwater harvesting. Addressing these disparities requires gender-sensitive interventions that enhance women’s access to resources, empower their decision-making, and strengthen resilience in water-scarce environments.

Generational disengagement was another concern. Few young people are active in home gardening, reducing intergenerational knowledge transfer and weakening adaptive capacity (Leavy and Hossain, 2014; Geza et al., 2021). As one youth participant in Msobomvu (FGD4, April 2024) noted: “Farming is for older people here; we look for work in town because gardens do not bring income.” This sentiment highlights a growing perception gap between older and younger generations regarding the value of household crop production. While older participants described gardens as essential for food security, young people tended to view them as labor-intensive and economically unrewarding. Migrating to big cities in search of employment opportunities further erodes youth participation in household food production (Adom et al., 2023; Mdoda et al., 2024; Tantoh and McKay, 2023). Therefore, policies and programs need to make agriculture more appealing to younger

generations by linking home gardening with skills development and entrepreneurship.

Despite widespread irrigation, uptake of water-saving practices such as mulching and drought-tolerant varieties was modest. Education showed strong associations with these practices, confirming that access to knowledge shapes household adaptation (Autio et al., 2021; Sanchez et al., 2012; Aina et al., 2023). However, a disjuncture was observed: households actively used adaptive practices but reported low awareness of formal Climate-Smart Agriculture (CSA) frameworks. Traditional practices such as manuring were more common among those without CSA awareness, illustrating the value of indigenous knowledge often overlooked in CSA discourse (Chandra et al., 2018). Bridging this divide through knowledge integration and targeted education could strengthen household resilience and the sustainability of smallholder farming systems.

Qualitative accounts deepened these insights. Participants stressed the unreliability of municipal water for irrigation: “When the taps run dry, we fetch from the river. Rainwater tanks help, but they are small” (FGD1, Msobomvu, April 2024). Rainwater harvesting was valued but constrained by cost and technical knowledge (Kelemewerk Mekuria et al., 2020; Mtyelwa et al., 2022). Adding to these barriers were erratic weather, pests, and time constraints. Such narratives highlight the everyday trade-offs households make to sustain food under uncertainty.

5.1 Study limitations and areas for further research

This study has several limitations that should be acknowledged. First, the cross-sectional design limits the ability to establish causal relationships between socio-demographic characteristics, water scarcity experiences, and adaptive practices; the chi-square test identifies associations only. Second, the study was conducted in a single village, Msobomvu, which constrains the generalizability of findings to other contexts with different socio-ecological and institutional conditions. Third, while efforts were made to ensure proportional representation in both survey and focus group samples, self-reported data may be subject to recall bias and social desirability bias. Finally, the study focused primarily on household-level and community-based responses without examining broader institutional or policy-level influences on water use and home gardening. Future research could address these limitations by conducting longitudinal studies to capture seasonal and inter-annual dynamics of water scarcity and adaptation. Comparative studies across multiple villages or municipalities would also provide insights into contextual variations in adaptation strategies. In addition, integrating policy analysis and institutional perspectives would enrich understanding of how governance and resource management frameworks shape household and community adaptation.

6 Conclusion and recommendations

The study shows that rural households in Msobomvu village, Eastern Cape, South Africa, are coping with persistent water scarcity through a combination of traditional knowledge

and low-cost innovations such as manuring, irrigation, and rainwater harvesting. Notwithstanding these strategies, female-headed households continue to be disproportionately vulnerable, but education and social grants are significant factors influencing adaptive capacity. Strengthening resilience therefore requires targeted interventions that prioritize inclusive extension services, gender-responsive support, and increased access to cost effective water-saving technologies adapted to local conditions. Household food production, particularly through home gardens, offers a more dependable and controllable means of ensuring food security compared to extensive field farming. Therefore, policy frameworks must connect national climate resilience initiatives with community/level realities by promoting home food gardens. Given the empirical and location-specific nature of this study, findings should not be overgeneralized but can inform context-driven adaptation in similar semi-arid settings. Future research should examine long-term adaptation trends and assess the outcomes of policy interventions in comparable rural communities.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Inter-Faculty Human Research Ethics Comm, University of Fort Hare. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

Author contributions

LZ: Investigation, Writing – original draft, Software, Funding acquisition, Formal analysis, Writing – review & editing, Resources, Methodology, Data curation, Visualization, Project administration, Conceptualization, Validation, Supervision. SMh: Project administration, Validation, Funding acquisition, Writing – review & editing, Supervision, Formal analysis, Software, Data curation, Investigation, Conceptualization, Resources, Visualization, Methodology, Writing – original draft. MS: Investigation, Methodology, Writing – review & editing, Supervision, Funding acquisition, Software, Writing – original draft, Resources, Conceptualization, Validation, Visualization, Data curation, Project administration, Formal analysis. SMu: Conceptualization, Project administration, Funding acquisition, Methodology, Writing – review & editing, Supervision, Validation, Writing – original draft, Investigation, Visualization, Software, Data curation, Formal analysis, Resources. AD: Validation, Funding acquisition, Writing – review & editing, Data curation, Project administration, Resources, Conceptualization, Writing – original draft, Methodology, Software, Visualization, Investigation, Formal analysis, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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