Broad portfolios, constrained transformation: Climate adaptation among agro-pastoral households in semi-arid Tanzania

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ABSTRACT

Climate adaptation in dryland agriculture is often assessed by counting individual practices, although the distribution of practices across households may conceal whether adaptation is sustained, effective or institutionally supported. This study examines the adaptation portfolio reported by agro-pastoral households in Bahi and Mpwapwa districts of semi-arid central Tanzania and identifies the institutional conditions that shape its depth. This study is guided by the Pressure and Release (PAR) model and Open Systems Theory. A convergent mixed-methods design combined a household survey of 305 randomly selected agro-pastoral households with 24 key informant interviews and four focus group discussions involving 40 participants. Descriptive statistics and village-level chi-square tests were integrated with thematic analysis. Most respondents perceived declining rainfall (91.1%) and increasing temperature (85.9%). Reported adaptation was extensive but concentrated in practices that could be implemented through household labour, existing assets and local knowledge: crop rotation (95.0%), adjustment of planting dates (88.6%), conservation agriculture (87.8%), intercropping (80.8%), use of climate information (80.3%), crop-residue feeding (79.0%) and seasonal livestock migration (76.9%). Practices requiring finance, infrastructure, secure land or specialized inputs were markedly less common, including small-scale irrigation (34.2%), introduction of new crops (30.1%) and access to credit (19.2%). Extension officers were the main reported source of adaptation knowledge (59.5%), followed by peer learning (27.6%) and local experience (12.9%). Qualitative evidence linked uneven adoption to irregular input supply, weak markets and storage, limited extension coverage, financial exclusion and competition over land and water. The findings indicate a broad but predominantly incremental adaptation portfolio, reflecting constrained transformation: households responded actively to climatic stress, yet persistent resource and institutional constraints limited their ability to sustain, combine and scale responses. This suggests that portfolio breadth alone is an insufficient indicator of adaptive depth. Strengthening adaptation therefore requires more than promoting additional practices: it requires localized climate services, reliable extension, finance linked to viable technologies, market and storage support, and negotiated land and water governance. Because the study is cross-sectional and practice adoption was self-reported, the results establish patterns of adaptation rather than causal evidence of reduced climate risk.

Keywords: Adaptive Capacity; Agro-Pastoralism; Climate Information Services; Drylands; Institutional Constraints; Tanzania

I. INTRODUCTION

Agro-pastoral systems in semi-arid areas are exposed to interacting climatic, ecological and institutional pressures (Huang et al., 2016; Singh & Chudasama, 2021). Rainfall variability affects crop establishment, pasture growth and water availability, while rising temperatures increase evaporative demand and heat stress. Because crop and livestock enterprises share land, labour, water and household capital, a shock in one component can rapidly affect the other. Adaptation in such systems is therefore not a single technical decision, but a portfolio of crop, livestock, mobility, information, water, land and livelihood responses assembled under changing constraints.

The distinction between the number of reported practices and the depth of adaptation is important. A global stocktake found that implemented adaptation is commonly local, fragmented and incremental, with limited evidence that reported actions actually reduce climate risk (Berrang-Ford et al., 2021). In this paper, adaptive depth refers to the extent to which an adaptation portfolio moves beyond short-term coping to support sustained risk reduction, strengthen the capacity to absorb and recover from climate shocks, and, where necessary, enable changes in livelihood or production-system functions that reduce underlying vulnerability. Portfolio breadth therefore describes the range of practices used, whereas adaptive depth concerns their capacity to generate durable resilience outcomes. The presence of several practices cannot consequently be interpreted automatically as successful or transformative adaptation. The ability to maintain, combine and revise these practices depends on access to information, finance, infrastructure, markets, land and legitimate institutions. Interventions that overlook these vulnerability contexts may redistribute or reinforce vulnerability rather than reduce it (Eriksen et al., 2021).

Comparable evidence from other semi-arid regions shows that widespread adaptive responses do not necessarily translate into deeper or transformational adaptation. In the Sahel, farmers responded to changing rainfall by reintroducing locally suitable crop varieties, but adoption remained uneven and constrained by differences in resources and opportunities (Lalou et al., 2019). Longitudinal evidence from semi-arid India similarly shows that household resilience to climatic risk is shaped by livelihood diversification, liquidity and borrowing capacity (Kumar et al., 2020). In Brazil's semi-arid Sertao, small-scale irrigation improved production opportunities but its sustained use was constrained by unreliable water availability, particularly during severe drought (Burney et al., 2014). Together, these studies indicate that adaptation across semi-arid systems depends not only on the adoption of practices but also on the resources and institutional conditions that enable them to persist and reduce vulnerability.

Across African smallholder systems, common responses include changing planting dates, crop diversification, drought-tolerant varieties, soil and water conservation, livestock mobility and livelihood diversification (Intergovernmental Panel on Climate Change [IPCC], 2022). Evidence from semi-arid Tanzania similarly documents intercropping, changes in planting calendars, improved or drought-tolerant crops, migration and land-use adjustment (Mkonda, 2022; Msilu et al., 2026; Myeya, 2021b). Much of this evidence, however, identifies individual practices and the socioeconomic factors associated with their adoption. This leaves an important gap between adaptation-counting approaches, which infer adaptive progress from the presence or number of responses, and vulnerability-oriented perspectives, which question whether those responses produce sustained reductions in climate risk. Less is known about how multiple practices combine within household adaptation portfolios, or where the threshold lies between low-cost autonomous adjustments and adaptations that depend on sustained institutional, financial and infrastructural support.

Climate information illustrates this distinction. Forecasts can improve decisions on crop choice, planting time and input allocation, but information is useful only when it is local, understood, trusted and connected to feasible actions. Recent African reviews show that education, advisory services, communication channels, social networks and household resource endowments shape access to and uptake of climate information services (Nyoni et al., 2024; Appiah et al., 2025). Evidence from Tanzania also demonstrates the value of rainfall-onset information for crop risk management while emphasizing the importance of extension support and effective dissemination (Hersi et al., 2023; Msilu et al., 2024; Joseph et al., 2025). Thus, receiving a forecast does not by itself constitute deep adaptation if households lack the seed, labour, credit, water or institutional support required to translate information into sustained risk reduction. Accordingly, this study examines the breadth and adaptive depth of adaptation portfolios among agro-pastoral households in Bahi and Mpwapwa districts, with particular attention to the practices adopted, the knowledge and institutional support underpinning them, and the barriers that constrain movement from incremental responses towards more sustained adaptation.

1.1 Statement of the Problem

Although agro-pastoral households in semi-arid Tanzania employ multiple strategies to manage climatic variability, existing studies have largely documented individual adaptation practices and the socioeconomic factors associated with their adoption. Such evidence is important, but the presence or number of practices does not establish whether adaptation is sustained, complementary or capable of reducing vulnerability over time. Studies from Tanzania have documented changes in planting calendars, crop diversification, livestock mobility, climate-information use and other responses, yet less attention has been given to how these practices combine within household adaptation portfolios and how institutional and resource constraints shape their adaptive depth.

This creates an important empirical gap because households may report numerous responses while remaining unable to sustain, combine or scale them because of limited finance, water, land, infrastructure, markets, extension services or access to actionable climate information. Consequently, counting adaptation practices may overstate adaptive capacity where responses remain predominantly autonomous and incremental. This study addresses this gap by examining the composition of agro-pastoral adaptation portfolios in Bahi and Mpwapwa, the knowledge and institutional support associated with them, and the constraints affecting movement towards more sustained adaptation.

1.2 Research Questions

i. What crop, livestock, climate-information and livelihood adaptation practices constitute the reported adaptation portfolios of agro-pastoral households?
ii. How do knowledge sources and institutional support enable household adaptation practices?
iii. What resource and institutional constraints limit households' capacity to sustain, combine and scale adaptation practices?

II. LITERATURE REVIEW

2.1 Theoretical Review

This study is guided by the Pressure and Release (PAR) model and Open Systems Theory. The PAR model explains vulnerability as the interaction between hazards and underlying social, economic and institutional conditions that constrain people's capacity to respond (Blaikie et al., 2004). In agro-pastoral systems, limitations in access to land, water, finance, markets, extension services and productive assets can therefore increase vulnerability even where households actively respond to climatic stress. This perspective is relevant to the present study because the manuscript identifies financial exclusion, irregular input supply, weak markets, inadequate extension and competition over land as important constraints to adaptation.

Open Systems Theory views livelihood systems as interconnected with their wider institutional and economic environment (von Bertalanffy, 1968). Agro-pastoral households depend on continuous flows of climate information, extension services, inputs, finance, water and markets. Adaptation can consequently be constrained when these flows are weak or disconnected. The two perspectives are complementary: the PAR model helps explain the structural conditions that constrain adaptation, while Open Systems Theory highlights the reliability of the institutional and resource flows required to sustain adaptation. This framework supports the paper's distinction between a broad portfolio of reported responses and the capacity to sustain, combine and scale those responses.

2.2 Empirical Review

Agro-pastoral households in semi-arid environments commonly respond to climate variability through combinations of crop, livestock and livelihood practices. Frequently reported strategies include changing planting dates, crop diversification, drought-tolerant varieties, soil and water conservation, livestock mobility and livelihood diversification (IPCC, 2022). Similar responses have been documented in semi-arid Tanzania, including intercropping, changes in planting calendars, improved crop varieties, livestock migration and land-use adjustment (Myeya, 2021b; Mkonda, 2022; Msilu et al., 2026). However, much of this literature focuses on individual practices rather than how several responses form an adaptation portfolio.

The number of adaptation practices used by a household does not necessarily indicate the depth or effectiveness of adaptation. Global evidence shows that many implemented responses remain local and incremental, with limited evidence that they produce sustained reductions in climate risk (Berrang-Ford et al., 2021). Evidence from semi-arid India, the Sahel and Brazil also demonstrates that adaptation is shaped by household resources, liquidity, water availability and institutional support (Lalou et al., 2019; Kumar et al., 2020; Burney et al., 2014).

Knowledge and institutional support are equally important. Climate information can influence planting, crop selection and livestock decisions, but its usefulness depends on whether information is timely, locally relevant and linked to feasible actions. Extension services, social networks, finance, input availability, markets and access to land and water therefore influence households' capacity to act on available information (Nyoni et al., 2024; Appiah et al., 2025; Joseph et al., 2025). Existing Tanzanian studies provide substantial evidence on climatic change and individual adaptation practices, but less attention has been given to how these practices combine within household portfolios and how institutional and resource constraints affect their sustainability. This study addresses that gap by examining adaptation portfolio breadth together with the conditions that enable or constrain households' capacity to sustain, combine and scale adaptation responses.

III. METHODOLOGY

3.1 Study Area

The study was conducted in Bahi and Mpwapwa districts in Dodoma Region, central Tanzania. The region has a semi-arid climate characterized by a long dry season and a shorter, variable wet season. Agro-pastoral livelihoods integrate rain-fed crop production with livestock keeping and depend strongly on seasonal water and pasture. The selected villages were Mpamantwa and Mwitikira in Bahi District and Nghambi and Seluka in Mpwapwa District. The study employed a multistage site-selection procedure. Bahi and Mpwapwa districts were purposively selected because of their semi-arid agro-ecological conditions, predominance of agro-pastoral livelihoods and exposure to climate variability. Within the selected districts, study wards and villages were subsequently selected according to the sampling procedure described in Section 3.2.

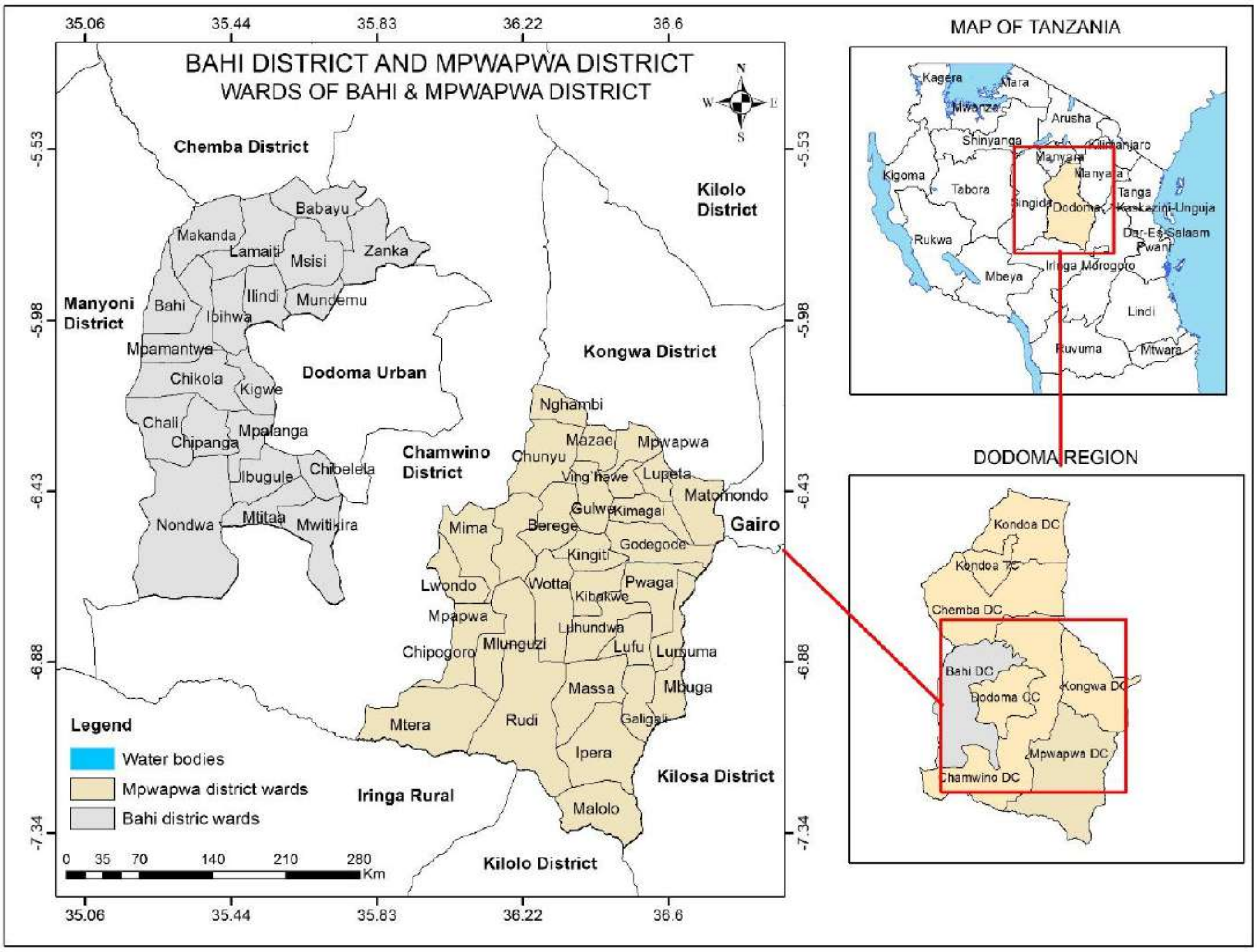

Figure 1

Location of Bahi and Mpwapwa Districts and the Study Wards in Central Tanzania

Source: author map prepared for the underlying doctoral study (2021).

3.2 Research Design and Sampling

The study used a convergent mixed-methods design within a wider investigation of climate variability and agro-pastoral systems. The quantitative component was a cross-sectional household survey. The qualitative component comprised key informant interviews, focus group discussions and field observation. Integration occurred during interpretation, where qualitative evidence was used to explain differences in reported practices and the institutional conditions surrounding them.

The household sampling frame contained 1,292 agro-pastoral households listed in village registers. The sample size was determined using Yamane's formula,

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

Where n is the required sample size, N is the population size and e is the level of precision. Using N=1,292 and e=0.05 yielded a sample of approximately 305 households. Proportionate allocation yielded 86 respondents in Mpamantwa, 76 in Mwitikira, 93 in Nghambi and 50 in Seluka. All 305 selected households completed the survey, corresponding to a 100% response rate; no refusals were recorded. Households were selected randomly from the village registers. The sampling procedure involved multiple stages. Bahi and Mpwapwa districts were purposively selected, after which the study wards and villages were selected within the two districts. At household level, the sampling frame comprised 1,292 agro-pastoral households listed in the selected village registers. The required sample was proportionately allocated among the four villages, and individual households were randomly selected from the respective village registers.

Twenty-four key informants were purposively selected based on their institutional responsibilities and knowledge of crop production, livestock management, land use and local governance. The sample included one district-level official responsible for agriculture, livestock and fisheries from each of the two study districts (n=2); four Ward

Executive Officers; four village chairpersons; four Village Executive Officers; four livestock extension officers; four agricultural extension officers; and two representatives of livestock keepers' associations. District-level officials were selected because their positions provided oversight of agricultural and livestock development within the respective districts, while the remaining informants were selected for their direct roles in service delivery, local governance or agro-pastoral resource management.

Four focus group discussions were conducted, one in each study village, involving a total of 40 participants. These comprised nine participants in Nghambi (4 men and 5 women), eleven in Seluka (6 men and 5 women), eight in Mpamantwa (3 men and 5 women), and twelve in Mwitikira (5 men and 7 women). Participants were purposively selected to include women and men with direct experience of crop production, livestock keeping and climate-related livelihood challenges. The selection aimed to capture diversity in livelihood roles and experiences rather than to achieve statistical representation of the village populations.

3.3 Data Collection

A researcher-administered questionnaire collected household demographic data, perceptions of rainfall and temperature change, reported adaptation practices, sources of climate information, sources of adaptation knowledge and access to selected institutional resources. Adaptation questions permitted multiple responses because households commonly used more than one practice. The questionnaire was translated into Swahili and pre-tested with a small group from the target population before the main survey. Pre-testing was used to identify ambiguous items and refine the wording and sequencing of questions to improve clarity and relevance. The questionnaire was subsequently administered in Swahili during household interviews.

Key informant interviews used a semi-structured checklist covering observed climatic stress, agricultural and livestock practices, extension and veterinary services, climate information, land and water governance, market conditions, projects and local government support. Focus group discussions explored changes in seasonal calendars, crop choice, mobility, feed management, livelihood diversification, indigenous forecasting and barriers to adoption. With permission, interviews were recorded and transcribed. Field observation was used to document environmental conditions and selected practices.

3.4 Measures and Analysis

The main quantitative outcomes were the proportions of respondents reporting each practice. Village-level percentages were compared using chi-square tests where complete statistics were available in the source tables. Because the survey allowed multiple responses, percentages across practices are not expected to sum to 100%. The term adoption is used to denote reported use of a practice, not verified duration, intensity or effectiveness. Survey data were processed in IBM SPSS Statistics version 25 and Microsoft Excel. Qualitative material was transcribed, coded and organized into recurring themes. The analysis focused on the mechanisms supporting or constraining practices: affordability and availability of inputs, extension contact, climate-information specificity, peer learning, market and storage conditions, land competition, water availability and access to finance. Findings were triangulated across household responses, focus groups, key informants and observation. The quantitative analysis reported in this paper was therefore limited to descriptive statistics and village-level chi-square tests.

3.5 Ethical Considerations

Research clearance was obtained from the University of Dar es Salaam, followed by permissions at regional, district and village levels. Participants were informed about the purpose and intended use of the research, confidentiality and the voluntary nature of participation. Informed consent was obtained before interviews, audio recording or photography. Quotations are identified only by participant category and study location.

IV. FINDINGS & DISCUSSION

4.1 Household Profile and Perceived Climatic Change

The sample (Table 1) was predominantly male (66.2%), reflecting the household-head orientation of the survey and local patterns of representation in agro-pastoral decision-making. Women constituted 33.8% of respondents, with the lowest representation in Seluka (18.0%) and the highest in Mpamantwa (41.9%). Most respondents were between 40 and 61 years of age: 38.4% were aged 40-50 and 35.4% were aged 51-61. Primary education was the highest level attended by 83.0% of respondents, while 4.3% reported no formal education.

Perceived climatic change was consistent across the study population (Table 1). A total of 91.1% reported that rainfall had decreased, while 85.9% reported that temperature had increased. These responses describe lived experience and decision context rather than measured meteorological trends. In the wider study (Msilu et al., 2024; Myeya, 2021a), annual rainfall totals did not show a statistically significant monotonic trend, whereas temperature increased and intra-seasonal rainfall characteristics remained variable. The contrast helps explain why households may report decreasing rainfall when the principal livelihood signal is unreliable timing, dry spells or effective moisture rather than annual totals alone.

Table 1

Selected Characteristics and Climate Perceptions Of Surveyed Households (n = 305).

Characteristic	Category	Percent (%)
Sex	Male	66.2
	Female	33.8
	TOTAL	**100**
Age	18-28 years	7.2
	29-39 years	10.8
	40-50 years	38.4
	51-61 years	35.4
	62 years and above	8.2
	TOTAL	**100**
Education	No formal education	4.3
	Primary	83.0
	Secondary	7.9
	College	3.3
	University	1.6
	TOTAL	**100**
Climate perception	Rainfall perceived to be decreasing	91.1
	Temperature perceived to be increasing	85.9

4.2 Crop Adaptation Portfolio

Crop management was dominated by practices that could be implemented largely through adjustments in household labour, crop combinations and existing land as shown in Table 2.

Table 2

Reported crop adaptation practices by village (multiple responses, percent).

Practice	Nghambi	Mwitikira	Seluka	Mpamantwa	Mean	Chi-square	p-value
Crop rotation	95.7	89.5	96.0	98.8	95.0	14.46	0.0023
Changing planting dates	89.2	88.2	84.0	93.0	88.6	15.38	0.0015
Conservation agriculture	80.6	93.4	84.0	93.0	87.8	13.04	0.0045
Intercropping	80.6	81.6	82.0	79.1	80.8	10.48	0.0148
Drought-tolerant seed varieties	68.8	82.9	62.0	73.3	71.7	14.20	0.0026
Livestock manure application	50.5	46.1	46.0	38.4	45.2	8.43	0.0378
Introduction of new crops	41.9	31.6	20.0	26.7	30.1	17.58	0.0005

Note: df = 3 for each chi-square test. Percentages are the proportion of respondents in each village reporting the practice.

Crop rotation was reported by 95.0% of respondents (Table 2), followed by changing planting dates (88.6%), conservation agriculture (87.8%) and intercropping (80.8%). Drought-tolerant or early-maturing seed was reported by 71.7%. Livestock-manure application was less common (45.2%), and 30.1% reported introducing crops that they had not previously cultivated. Adoption differed significantly among villages for every crop practice shown in Table 2. The differences were not uniform. Crop rotation was lowest in Mwitikira (89.5%) but exceeded 95% in the other villages. Drought-tolerant seed ranged from 62.0% in Seluka to 82.9% in Mwitikira. The introduction of new crops ranged from 20.0% in Seluka to 41.9% in Nghambi. These patterns indicate that even widely known practices were mediated by local input supply, project exposure, land and market opportunity.

Focus groups explained the high prevalence of planting-date adjustment as a response to unreliable rainfall onset and interruption. Participants described moving planting from November or December towards late December and January, depending on the observed season. Crop rotation and intercropping combined food and cash crops such as maize, sorghum, millet, sunflower, groundnuts, cowpeas and beans. Respondents framed these combinations as a way to avoid complete crop failure and to meet both consumption and income needs. Drought-tolerant seed was obtained through farmer selection, neighbours and agro-vet shops. Its adoption was limited where recommended varieties were unavailable or unaffordable.

The reported conservation-agriculture category was grounded mainly in shallow ploughing, reduced soil disturbance and soil-moisture conservation using tools already available to households. It should therefore not be assumed to represent the complete package of minimum tillage, permanent soil cover and rotation used in some international definitions. This distinction matters when comparing adoption rates across studies.

4.3 Livestock, Feed and Land-Use Responses

In Table 3, findings shows that, livestock adaptation depended strongly on mobility and crop-livestock integration. Seasonal migration to access pasture and water was reported by 76.9% of respondents. Adoption varied from 69.7% in Mwitikira to 81.4% in Mpamantwa, but the difference among villages was not statistically significant ($p = 0.2670$). Focus groups described migration mainly between September and the beginning of the rainy season. Movement was supported by information exchanged among livestock keepers about water and pasture conditions in neighbouring areas.

Crop residues were used as livestock feed by 79.0% of respondents. This was the most widely reported feed-management practice, ranging from 65.6% in Nghambi to 94.0% in Seluka. Hay use was reported by 56.9%, improved grasses, forage or fodder trees by 49.3%, and zero grazing by 40.9%. Hay and improved forage showed statistically significant village differences, whereas crop-residue use and zero grazing did not at the 5% level. Participants linked residue use to the availability of harvested crops and to storage capacity. Households with large herds could exhaust residues before the next rainy season, while households without transport or storage were less able to conserve hay.

Wild water melons, known locally as "Manhenjere," and another variety called "Mahikwi" (*Citrullus vulgaris*), are two other feed types that are especially fed to animals to supplement food and water in drought times (see Plate 1). It was confirmed in all FGDs in the study area, specifically in FGDs in Nghambi, that the villagers cultivate these crops specifically to provide food for their cattle, particularly during periods of extreme drought. *Mahikwi* and *Manhenjere* (watermelons) are indigenous fruits that spontaneously develop and are consumed by cattle in drought seasons, serving as food and water sources for livestock. In addition, *Manhenjere* can be ingested by humans by combining them with millet flour and cooking, and served as food.

Plate 1
Mahikwi, A Locally Used Drought-Period Livestock Feed in the Study Area

Herd-management responses were less widespread than feed- and mobility-based strategies and reflected divergent approaches to managing livestock risk. Keeping a large number of livestock was reported by 41.5% of respondents (Table 3), distributing livestock across locations by 38.1%, and destocking by 36.4%. Significant village-level differences were observed for keeping large herds ($\chi^2 = 12.23$, $p = 0.0067$) and destocking ($\chi^2 = 53.056$, $p < 0.001$), whereas the distribution of livestock across locations did not differ significantly among villages ($\chi^2 = 2.36$, $p = 0.5009$). The particularly wide village variation in destocking, ranging from 11.8% to 58.0%, suggests that herd-reduction decisions were strongly conditioned by local circumstances. Herd accumulation may preserve wealth and buffer households against individual animal losses, but it can also increase pressure on limited pasture and water resources.

Conversely, destocking can reduce feed and water demand, although sales during periods of drought and depressed livestock prices may represent distress responses rather than planned adaptation. Given the cross-sectional design, the study cannot determine whether these strategies ultimately strengthened or reduced household resilience.

Shifting crop production to other areas was reported by 36.5% of respondents, with relatively limited variation among villages (28.9–45.3%) and no statistically significant difference ($\chi^2 = 4.892$, $p = 0.180$). Qualitative evidence indicated that this response was constrained by land availability and could transfer cultivation pressure to other areas. Small-scale irrigation was reported by 34.2% of respondents and varied significantly among villages, from 23.7% to 46.2% ($\chi^2 = 14.187$, $p = 0.003$), indicating substantial spatial differences in access to this option. Irrigation depended on the availability of water, pumps, canals and suitable riverine plots. Key informants further reported that although water-harvesting ponds existed in the study villages, many did not retain sufficient water throughout the dry season, while rooftop rainwater harvesting remained uncommon because of installation costs.

Table 3

Selected Livestock, Feed And Resource-Management Practices

Practice	Mean (%)	Village range (%)	Chi-square	p-value
Use of crop wastes and residues	79.0	65.6-94.0	3.094	0.3773
Seasonal livestock migration	76.9	69.7-81.4	3.95	0.2670
Use of hay	56.9	34.9-70.0	17.059	0.0006
Improved grasses, forages or fodder trees	49.3	39.5-60.2	14.113	0.0027
Keeping a large number of livestock	41.5	27.6-58.0	12.23	0.0067
Zero grazing	40.9	29.1-47.4	7.244	0.0645
Distributing livestock across locations	38.1	30.0-42.1	2.36	0.5009
Destocking	36.4	11.8-58.0	53.056	<0.001
Shifting crop production areas	36.5	28.9-45.3	4.892	0.180
Small-scale irrigation	34.2	23.7-46.2	14.187	0.003

4.4 Livelihood Diversification and Climate Information

Livelihood diversification was reported by 51.5% of respondents. Activities mentioned in focus groups included petty trade, beekeeping, wage labour and other non-farm income sources. Diversification spread income risk, but participation depended on start-up capital, market access, household labour and location. The survey recorded whether diversification was used, not its income share or stability, and therefore does not show whether it was sufficient to offset agricultural losses. Climate information was used by 80.3% of respondents, with relatively small differences across villages: 76.3% in Nghambi, 80.3% in Mwitikira, 82.0% in Seluka and 82.6% in Mpamantwa. Respondents used information to inform planting time and crop selection. Radio was the principal weather-information source (53%), followed by television (30%). Village meetings and SMS from the Tanzania Meteorological Authority each accounted for 4%, while 6% reported receiving weather information from no source.

High reported information use coexisted with dissatisfaction about spatial specificity. Focus groups and key informants stated that official forecasts were commonly issued for the district or a wider area and did not resolve ward- or village-level variation. Farmers therefore combined scientific forecasts with observations and information from experienced farmers. This hybrid use should not be interpreted as rejection of scientific information. It was a response to scale, timing and actionability limitations. Extension officers were the most frequently reported source of adaptation knowledge (59.5%). Peer learning accounted for 27.6%, and local knowledge and experience for 12.9%. The pattern shows that formal and informal knowledge systems were complementary. Extension supplied recommendations and transmitted district forecasts, while peers and experienced farmers translated information into local practice and circulated information about pasture, water and crop performance.

Table 4

Main Reported Sources of Adaptation Knowledge

Source	Percent
Extension officers	59.5
Fellow community members	27.6
Local knowledge and experience	12.9
Total	**100**

Note: Categories sum to 100% in the source table.

4.5 Portfolio Pattern and Institutional Constraints

Figure 2 brings the reported practices and selected enabling resources into one descriptive profile. The highest values are concentrated in practices that draw on household labour, existing crops and livestock, flexible timing, mobility and widely available communication channels. The lowest values are associated with credit, irrigation, introduction of new crops and land shifts. This distribution does not prove that every high-adoption practice is inexpensive or that every low-adoption practice is superior. It demonstrates a consistent resource gradient in the practices households were able to report at scale.

Qualitative evidence identified five connected constraints. First, improved seeds and other inputs were costly and irregularly stocked. Farmers could be aware of recommended varieties but unable to obtain them at the required planting time. Second, markets and storage were unreliable. Households reported selling crops or livestock at unfavourable prices when storage, buyers or cash were limited. Third, extension coverage was uneven. Although extension officers were the main source of knowledge overall, some focus groups reported contact only once in a season or less. Fourth, access to finance was limited: only 19.2% reported access to formal or informal credit. Village savings groups existed, but participation and trust were uneven. Fifth, competition among cultivation, grazing and fodder production constrained land-based responses and contributed to conflict.

Formal support included extension advice, subsidized fertilizer or livestock medicines, local government campaigns and the Ecosystem-Based Adaptation for Rural Resilience (EBARR) project in Nghambi. Informal support included seed exchange, peer demonstration, reciprocal information about pasture and water, and indigenous weather indicators. These forms of support interacted. A formal recommendation could spread through peer networks, while local observations could determine whether a district forecast was acted upon.

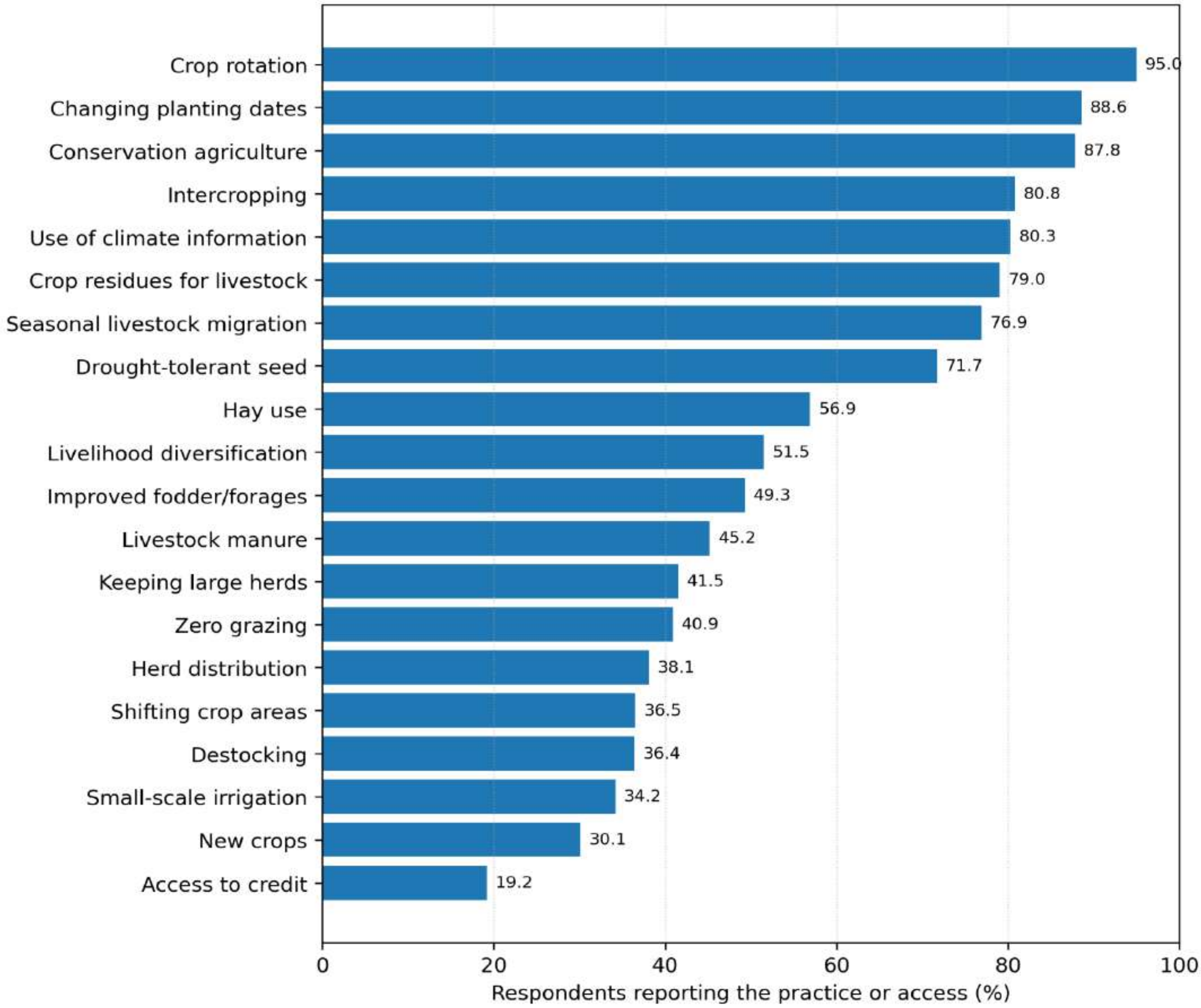

Figure 2

Reported Adaptation Practices and Access to Credit Among Surveyed Agro-Pastoral Households.

Figure 2. Reported adaptation practices and access to credit. Values are survey percentages drawn from the supplied study tables. Practices were measured as multiple responses; access to credit is an enabling-resource indicator rather than an adaptation practice.

4.6 Discussion

4.6.1 Broad Portfolio, Limited Evidence of Adaptive Depth

The central empirical finding is not a shortage of household response. Agro-pastoral households reported many changes across crop production, livestock management, mobility, feed, information and livelihoods. The pattern reinforces growing evidence that rural dryland households actively adjust livelihood practices in response to climatic stress, while also showing that such agency operates within significant resource and institutional constraints. Crop rotation, planting-date adjustment, intercropping, crop-residue feeding and mobility were already embedded in livelihood management and could be modified as seasonal conditions changed.

At the same time, breadth should not be equated with depth. The most prevalent responses were predominantly incremental and could be implemented using existing labour, land-use knowledge, crops, livestock and social relations. Practices requiring major capital, assured water, secure land, storage, specialized inputs or reliable markets were less common. This finding is consistent with global evidence that implemented adaptation remains mainly local and incremental (Berrang-Ford et al., 2021). It also extends Tanzanian studies that document common farm-level responses by showing how the practices are distributed along an institutional and resource gradient (Mkonda & He, 2018; Myeya, 2021; Mkonda, 2022).

The term constrained transformation is used here to describe a condition in which households demonstrate substantial adaptive effort and diversify their responses, but remain unable to make more durable changes because access to finance, water, land, markets, infrastructure and sustained institutional support is limited. It does not imply that households have undergone transformational adaptation or shifted from one production system to another. Rather, it captures the gap between a broad repertoire of incremental responses and the capacity to sustain, combine or scale those responses in ways that could materially reduce long-term vulnerability. In practical terms, greater adaptive depth would be indicated by sustained use of practices across seasons, demonstrable reductions in climate-related losses, improved capacity to recover after shocks, and the ability to maintain complementary adaptation practices over time.

4.6.2 Crop-Livestock Integration and Mobility as System Responses

The high use of crop residues and manure illustrates the integrated logic of agro-pastoral production. Residues extend feed supply after harvest, while manure can return nutrients to cultivated land. This cycling can reduce dependence on purchased inputs, but it is bounded by crop yield, herd size, labour and storage. A poor crop season simultaneously reduces household food and livestock feed, showing why the apparent complementarity can become a shared point of failure. Seasonal livestock mobility remained one of the most widespread responses. Similar evidence from East African pastoral systems shows that mobility enables access to spatially variable pasture and water (Megersa et al., 2014; Bostedt et al., 2023). The present findings add a governance dimension. Mobility depended on information exchange, access arrangements and relations with receiving communities. It could relieve pressure in the home village, but increasing herd numbers and resource scarcity could also intensify conflict. Policies that restrict movement without providing reliable feed and water alternatives may therefore remove an adaptive option, while unregulated movement can transfer environmental pressure and conflict. Negotiated corridors, water-point governance and reciprocal local agreements are more consistent with the observed system.

The strong variation in destocking across villages indicates that herd reduction is highly context dependent. This is consistent with Bostedt et al. (2023), who found substantial spatial variation in herd-reduction strategies among pastoral communities in Kenya and showed that reducing herds may represent either a reactive response to crisis or a more anticipatory adjustment. Similarly, evidence from southern Ethiopia shows that severe drought can lead to both livestock mortality and forced off-take, demonstrating that reductions in herd size do not necessarily represent planned adaptation (Megersa et al., 2014). The present findings extend this evidence by showing that, within the same semi-arid agro-pastoral setting, destocking ranged from 11.8% to 58.0%, suggesting that market conditions, pasture availability, herd assets and local livelihood circumstances strongly condition the strategy.

4.6.3 Climate Services as an Information-to-Action Chain

The reported use of climate information was high, but the pathway from receipt to action was incomplete. Radio and television provided reach, while extension officers and local networks helped interpretation. The weakness was localization. District-scale forecasts did not always correspond to village-level rainfall onset or distribution, and farmers supplemented them with local observation. Evidence from Kenya illustrates the value of more localized climate services. In Kitui County, decentralized seasonal forecasts and advisories provided more disaggregated and contextualized information than national-level products and were associated with modestly higher household productive income

(Barrett et al., 2021). Similarly, co-created climate services in Kajiado and Kiambu counties showed the value of tailoring information to specific crops, local conditions and user needs through a bottom-up approach (Van der Horst et al., 2022). These experiences support the need to move beyond broad-area forecasts towards climate information that is locally relevant and linked to concrete livelihood decisions.

This suggests that climate services should be assessed as an information-to-action chain. The first link is forecast quality and spatial-temporal relevance. The second is communication in accessible language and through trusted channels. The third is interpretation for specific crop and livestock decisions. The fourth is response capacity, including seed, labour, finance, water and market options. Joseph et al. (2025) demonstrate the agronomic and economic potential of rainfall-onset forecasts for maize and sorghum in Kongwa, Tanzania, but also emphasize improved dissemination and extension. The current study shows why these supporting functions matter at household level. A practical implication is that extension messages should be organized around decision calendars rather than general climate awareness. Before the season, households need probabilistic onset information linked to crop and seed options. During the season, they need updated advice on dry spells, replanting, pests, water and feed. Before the dry season, livestock keepers need coordinated information on pasture, water and movement conditions. Such services should incorporate local observations as a source of contextual interpretation while retaining transparent scientific uncertainty.

4.6.4 Structural Pressures and the Risk of Maladaptation

Consistent with the PAR model (Blaikie et al., 2004), the principal constraints can be interpreted through the progression from limited resources and services to unsafe production conditions. Financial exclusion, irregular input supply, weak storage and markets, inadequate extension and competition over land convert climate variability into avoidable losses. Households respond through practices available within those conditions, but some responses can transfer risk. Expanding cultivation may reduce short-term food shortage while increasing pressure on grazing land. Moving herds may protect animals while increasing conflict elsewhere. Selling livestock may meet immediate cash needs while reducing future productive assets.

These risks align with the wider warning that adaptation interventions can reinforce or redistribute vulnerability when they are introduced without sufficient attention to local power, resource access and livelihood trade-offs (Eriksen et al., 2021). For example, irrigation may increase production and reduce rainfall dependence, but poorly managed schemes can create new ecological risks. In the semi-arid Gumselassa irrigation scheme in northern Ethiopia, inadequate on-farm and scheme-level water management was associated with worsening water scarcity, declining crop yields and soil salinization (Yohannes et al., 2017). Similarly, a programme promoting improved forage may have limited or unintended effects where households must divert scarce land from communal grazing or food production. The implication is that the objective should not be to maximize technology uptake, but to reduce climate risk while avoiding new financial, ecological or social exposure.

Open Systems Theory (von Bertalanffy, 1968) directs attention to the reliability of flows. Extension was highly important as a knowledge source, yet intermittent contact weakened feedback. Climate information reached households, yet its general spatial scale reduced actionability. Subsidies and projects provided inputs or infrastructure, but coverage was uneven. Markets existed, yet weak storage and bargaining power reduced returns. In this sense, adaptation was constrained less by the absence of individual components than by discontinuity between them.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

Agro-pastoral households in Bahi and Mpwapwa reported extensive behavioural responses to climatic uncertainty. Crop rotation, flexible planting dates, conservation practices, intercropping, crop-residue feeding, mobility and climate information were widespread. The adaptation portfolio was therefore broad, but its distribution was uneven. Practices dependent on finance, infrastructure, land, specialized inputs or stable markets remained much less common.

The evidence does not support a claim that households lack awareness or initiative. It shows that adaptive depth is limited by the systems through which knowledge, finance, inputs, water, land and market opportunities reach households. Viewed through the PAR model and Open Systems Theory, these findings show that adaptive depth is shaped not only by climatic exposure, but also by structural pressures and discontinuities in the flows of information, services and resources needed to sustain and combine adaptation responses. Future research should use longitudinal and comparative designs to examine whether adaptation portfolios persist across seasons, reduce climate-related losses and support recovery, and how these outcomes vary across agro-ecological and institutional contexts. Strengthening adaptation therefore requires coherent institutional support that makes climate information actionable, protects mobility and common resources, improves extension continuity, and enables households to invest without creating new vulnerability.

5.2 Recommendations

The findings support five linked priorities for local government, climate-service providers and development partners. These priorities should be designed as a package because isolated interventions are unlikely to address the observed bottlenecks. Localize climate services. Produce ward- or livelihood-zone advisories where data permit, communicate forecast uncertainty, and link onset and dry-spell information to crop, replanting, feed and livestock-movement decisions. Strengthen extension continuity. Combine field contact, village meetings, radio and mobile communication, while using trained lead farmers and livestock-keeper networks to extend reach without presenting peer advice as a substitute for professional services.

Finance feasible bundles. Link appropriately structured credit or grants to verified needs such as drought-tolerant seed, water lifting, hay storage, fodder establishment and small-scale irrigation. Financing should be timed to seasonal cash flow and accompanied by technical and market support. Reduce market and storage constraints. Support collective storage, market information, producer organization and planned livestock marketing so that households are not forced to sell crops or animals at the least favourable time. Govern land, water and mobility collectively. Use participatory land-use planning to protect grazing areas and movement routes, clarify access to water points, prevent cultivation of critical commons and establish dispute-resolution mechanisms across village boundaries. Monitoring should move beyond counts of trained households or technologies distributed. At minimum, programmes should track sustained use, timing and intensity of practices, distribution of benefits by sex and wealth, changes in crop and livestock losses, conflict incidence, asset recovery after drought, and any transfer of pressure to other land or groups. This would address the current evidence gap between reported implementation and demonstrated risk reduction.

Declaration of Interest

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