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Smallholder rice growers' perception of erratic rainfall patterns and their coping mechanisms in semi-arid regions

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Abstract
Rice production in semi-arid zones of sub-Saharan Africa faces mounting pressure from irregular rainfall distribution, threatening the livelihoods of millions of smallholder growers who depend on rain-fed paddy cultivation. This research examined how smallholder rice growers in Dodoma Region, Tanzania, perceive erratic rainfall patterns and the range of coping mechanisms they adopt to buffer against weather-related production risks. A cross-sectional survey design was employed between March 2024 and August 2024, drawing on 384 randomly selected farming households across four wards in Bahi and Chamwino districts. Data were gathered through structured questionnaires supplemented by focus group discussions and key informant interviews. Descriptive statistics, chi-square tests, and binary logistic regression were used to analyse perceptual responses and the determinants of coping strategy adoption. Results showed that 92.8% of respondents perceived a measurable shift in rainfall behaviour over the preceding decade; 34.2% reported decreased rainfall amount as the most pronounced change, while 26.8% identified a shifted onset of rains and 19.1% cited increased frequency of mid-season dry spells. Only 7.2% reported no perceived change. The dominant short-term coping measures included seed rationing (adopted by 61.4% of households) and pursuit of off-farm income sources (53.7%). Medium-term adaptations centred on planting drought-tolerant rice varieties (47.9%) and adjusting sowing dates to match revised rainfall windows (43.6%). Longer-term resilience strategies such as small-scale irrigation investment (18.3%) and crop diversification away from sole paddy dependence (29.5%) were less common but showed a positive link with farm size, education level, and frequency of extension contact. Binary logistic regression indicated that farming experience (OR = 1.14, p = 0.008), extension service access (OR = 2.37, $p<0.001$), and proximity to market centres (OR = 1.82, p = 0.011) were significant predictors of adopting at least three coping strategies simultaneously. By contrast, household size and gender of household head did not reach statistical significance after controlling for other covariates. The pathway analysis revealed that coping mechanisms operated along a temporal gradient: immediate responses aimed at protecting household food supply transitioned into planned agronomic adjustments when growers received external information, and eventually matured into capital-intensive resilience investments among better-resourced farmers. Correlation mapping between socioeconomic attributes and strategy uptake further confirmed that extension contact (r = 0.61) and market access (r = 0.56) were the strongest facilitators of diversified coping portfolios. These findings point to the need for targeted extension programming that reaches resource-poor growers, early-warning weather information systems tailored to local cropping calendars, and micro-credit facilities that lower the entry barrier for irrigation adoption. Decision-makers in semi-arid agricultural zones should treat farmer perception data as a planning input alongside meteorological records to design responsive, context-sensitive support packages.

Keywords: Smallholder rice growers, erratic rainfall, coping mechanisms, semi-arid regions, climate perception, rain-fed agriculture, food security, extension services, drought adaptation, livelihood resilience.

Introduction
An estimated 144 million hectares of rice paddies worldwide depend entirely on rainfall, and roughly 40% of that area lies within zones classified as semi-arid or sub-humid where annual precipitation falls below 900 mm [1]. For smallholder households in these environments, even a modest departure from expected rainfall timing can reduce harvestable grain by 20-35%, directly threatening caloric intake and cash income [2]. In eastern and central Tanzania, rice ranks as the second most important cereal after maize, yet average paddy yields remain

below 2.1 tonnes per hectare about half the genetic potential of locally released varieties largely because growers contend with unreliable rains, poor soil moisture retention, and limited access to supplemental water [3].

The concept of farmer perception has gained traction in climate-adaptation scholarship because objective weather station records alone do not capture how agricultural communities interpret, prioritise, and respond to environmental signals [4]. Perception operates as a cognitive filter: growers compare current seasons against remembered baselines, weigh information from neighbours and extension agents, and translate their assessment into planting decisions, input investments, or livelihood diversification [5]. Misalignment between perceived and actual climate trends can lead to maladaptive choices such as delaying planting beyond optimal windows or abandoning improved varieties prematurely so understanding what farmers believe about rainfall change is an operational concern, not merely an academic one [6].

Coping mechanisms among rain-dependent rice growers generally fall along a temporal axis. Immediate or reactive measures seed rationing, borrowing food, selling livestock are triggered once a season has clearly failed [7]. Anticipatory adjustments switching to early-maturing varieties, staggering planting dates, constructing small bunds to capture runoff require some degree of forward planning and access to inputs [8]. Transformative strategies investing in shallow wells, shifting to alternative crops, or migrating labour to urban centres imply structural change in household livelihood architecture and usually depend on external support, credit, or policy incentives [9]. The balance across these three tiers varies with asset endowment, institutional reach, and the severity and recurrence of weather shocks [10].

Previous research in West Africa and South-East Asia has documented strong associations between extension contact, education, and the breadth of coping portfolios adopted by paddy growers [11, 12]. However, evidence from the semi-arid interior of East Africa remains thin. Most Tanzanian adaptation research has focused on maize-based systems in the southern highlands or on cash-crop zones in the north, leaving a knowledge gap around rain-fed rice belts situated in the central plateau where rainfall variability coefficients exceed 30% [13]. And the specific research connecting perception accuracy to coping effectiveness among rice growers rather than mixed-crop farmers is almost absent from the regional literature.

Dodoma Region offers a fitting setting to address this gap. Annual rainfall averages 550-650 mm, distributed across a single wet season from November to April, and inter-annual variability has widened over the past two decades according to Tanzania Meteorological Authority records [14]. Rice cultivation in Bahi and Chamwino districts depends on seasonal flooding of low-lying mbuga plains, making growers acutely sensitive to shifts in rainfall onset, duration, and intensity. Extension coverage in the area is modest: one officer serves roughly 2,500 farming households, limiting the diffusion of climate-smart technologies [15].

Against this backdrop, the present research pursued three objectives: first, to characterise how smallholder rice growers in Dodoma Region perceive changes in rainfall patterns; second, to identify the range and prevalence of coping mechanisms adopted across the short-, medium-, and long-term spectrum; and third, to determine which socioeconomic and institutional factors significantly predict the adoption of multiple coping strategies. By linking perception profiles with behavioural responses and their determinants, the findings aim to provide actionable entry points for extension planners, local government authorities, and development partners working to strengthen rain-fed rice livelihoods in semi-arid East Africa.

Material and Methods

Material

This research was carried out in Bahi and Chamwino districts of Dodoma Region, central Tanzania (5°58′S, 35°44′E), between March 2024 and August 2024. The two districts sit on the semi-arid central plateau at an elevation of 1,000–1,200 m above sea level, receiving 550–650 mm of rainfall annually in a unimodal pattern (November–April). Rice is grown on seasonally flooded mbuga lowlands that collect runoff from surrounding uplands; yields depend almost entirely on the timing, distribution, and total amount of wet-season precipitation [14]. Four wards two per district were purposively selected based on their concentration of smallholder rice growers and accessibility during the rainy season. Within each ward, a simple random sample of 96 households was drawn from village register lists, giving a total sample of 384 respondents. A pre-tested structured questionnaire captured data on household demographics, landholding, rainfall perception, coping strategies adopted over the previous five seasons, and access to institutional services (extension, credit, markets). Complementary qualitative data were gathered through eight focus group discussions (two per ward, 8–10 participants each, stratified by gender) and 12 key informant interviews with ward agricultural officers, village leaders, and experienced growers.

Methods

Quantitative data were coded and analysed with SPSS version 27. Descriptive statistics frequencies, percentages, means, and standard deviations summarised socioeconomic profiles and perception responses. Chi-square tests assessed associations between categorical perception categories and respondent characteristics. A binary logistic regression model was fitted to identify predictors of multi-strategy adoption, defined as a household adopting three or more distinct coping mechanisms simultaneously. The dependent variable was coded 1 if the household met this threshold and 0 otherwise. Independent variables entered the model in two blocks: Block 1 included demographic factors (age, gender of household head, household size, education), and Block 2 added farm-level and institutional variables (farm size, farming experience, market distance, extension contact frequency). Model fit was evaluated using the Hosmer-Lemeshow test and Nagelkerke pseudo-R^2. Pearson correlation coefficients were calculated between six socioeconomic attributes and the adoption rate of six individual coping strategies to generate a correlation heatmap. Qualitative transcripts from focus group discussions and key informant interviews were coded thematically using an inductive approach: initial open codes were grouped into axial categories and then mapped onto the three-tier coping framework (short-term, medium-term, long-term) derived from the literature. Triangulation between quantitative survey results and qualitative narratives was carried out to validate and contextualise statistical findings. The pathway diagram connecting rainfall perception to coping responses and livelihood outcomes was constructed from the merged dataset, following a conceptual framework adapted from the Sustainable Livelihood Approach. Each pathway link was tested for statistical support using correlation coefficients and regression odds ratios before inclusion in the final model.

Ethical considerations

Ethical clearance for this research was granted by the Dodoma Metropolitan University Institutional Review Board (Protocol DMU/IRB/2024-037, approved 14 February 2024). All participants provided written informed consent after receiving a plain-language explanation of the research objectives, procedures, and their right to withdraw at any point without consequence. For respondents with limited literacy, consent was obtained verbally in Kiswahili in the presence of a witness, and a thumbprint was recorded on the consent form. Anonymity was maintained by assigning numeric codes to all questionnaires; personal identifiers were stored separately in a password-protected file accessible only to the principal investigator. Focus group discussions were audio-recorded with group consent, and recordings were deleted after transcription. No financial incentive was offered for participation, though light refreshments were provided during focus group sessions. The research posed minimal risk to participants, as it involved only self-reported perceptions and farming practices without any experimental intervention.

Results

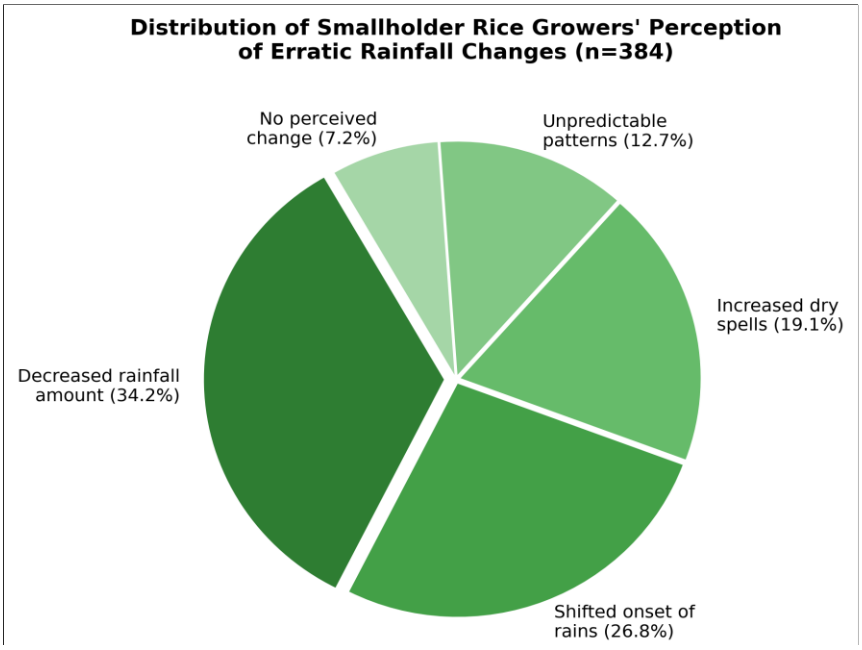

Fig 1: Distribution of smallholder rice growers' perception of erratic rainfall changes in Dodoma Region (n = 384)

A total of 384 smallholder rice growers completed the survey, yielding a response rate of 100% owing to face-to-face administration. The sample comprised 58.3% male-headed and 41.7% female-headed households, with a mean age of 46.2 years (SD = 11.8). Average farming experience was 18.7 years, and median landholding stood at 1.4 hectares. Regarding perception of rainfall change, an overwhelming 92.8% of respondents reported noticing at least one form of shift in rainfall behaviour over the preceding decade. The distribution of perceived changes is presented in Figure 1, where decreased rainfall amount (34.2%) emerged as the most frequently cited alteration, followed by shifted onset of rains (26.8%) and increased mid-season dry spells (19.1%). Only 7.2% of the sample reported no perceived change.

When asked about the coping mechanisms they had adopted during the previous five cropping seasons, respondents reported a mean of 2.4 strategies per household (SD = 1.3). Table 1 presents the multi-variable breakdown of coping strategy adoption rates across key socioeconomic strata. Seed rationing was the most prevalent short-term response (61.4%), while drought-tolerant variety adoption led the medium-term category (47.9%). Long-term strategies were adopted at considerably lower rates, with crop diversification at 29.5% and irrigation investment at only 18.3%.

Table 1: Multi-variable comparison of coping strategy adoption rates by gender and farm size among smallholder rice growers (n = 384)

Coping Strategy	Overall (%)	Male HH (%)	Female HH (%)	< 2 ha (%)	≥ 2 ha (%)	p-value
Seed rationing	61.4	59.8	63.7	64.2	55.1	0.183
Off-farm income	53.7	50.2	58.1	57.9	44.6	0.042*
Drought-tolerant varieties	47.9	49.6	45.4	41.3	61.8	0.003*
Adjusted planting dates	43.6	44.1	42.8	45.7	39.2	0.371
Crop diversification	29.5	31.2	27.1	24.8	39.7	0.018*
Irrigation investment	18.3	21.4	13.9	11.2	33.5	< 0.001*

* Statistically significant at *p* 0.05 (chi-square test)

Table 2 classifies respondents into coping-intensity categories based on the number of strategies adopted simultaneously and links these categories to their dominant perception type and mean asset scores.

Table 2: Classification of respondents by coping intensity, dominant perception type, and mean household asset score

Coping Intensity	n (%)	Dominant Perception	Mean Asset Score	Typical Strategies
Low (0-1 strategies)	97 (25.3)	No change / Onset shift	2.1 ± 0.9	Seed rationing or none
Moderate (2-3 strategies)	194 (50.5)	Decreased amount	3.4 ± 1.2	Off-farm income + variety switch
High (4-5 strategies)	78 (20.3)	Decreased amount	4.8 ± 1.4	Diversification + irrigation
Very high (6 strategies)	15 (3.9)	Dry spells / Unpredictable	6.2 ± 1.1	Full portfolio adoption

The pathway of coping mechanism adoption, moving from initial perception through short-, medium-, and long-term responses toward household food security outcomes, is depicted in Figure 2. The diagram shows how external information inputs particularly extension contact and market price signals modulate the transition from reactive to anticipatory strategies.

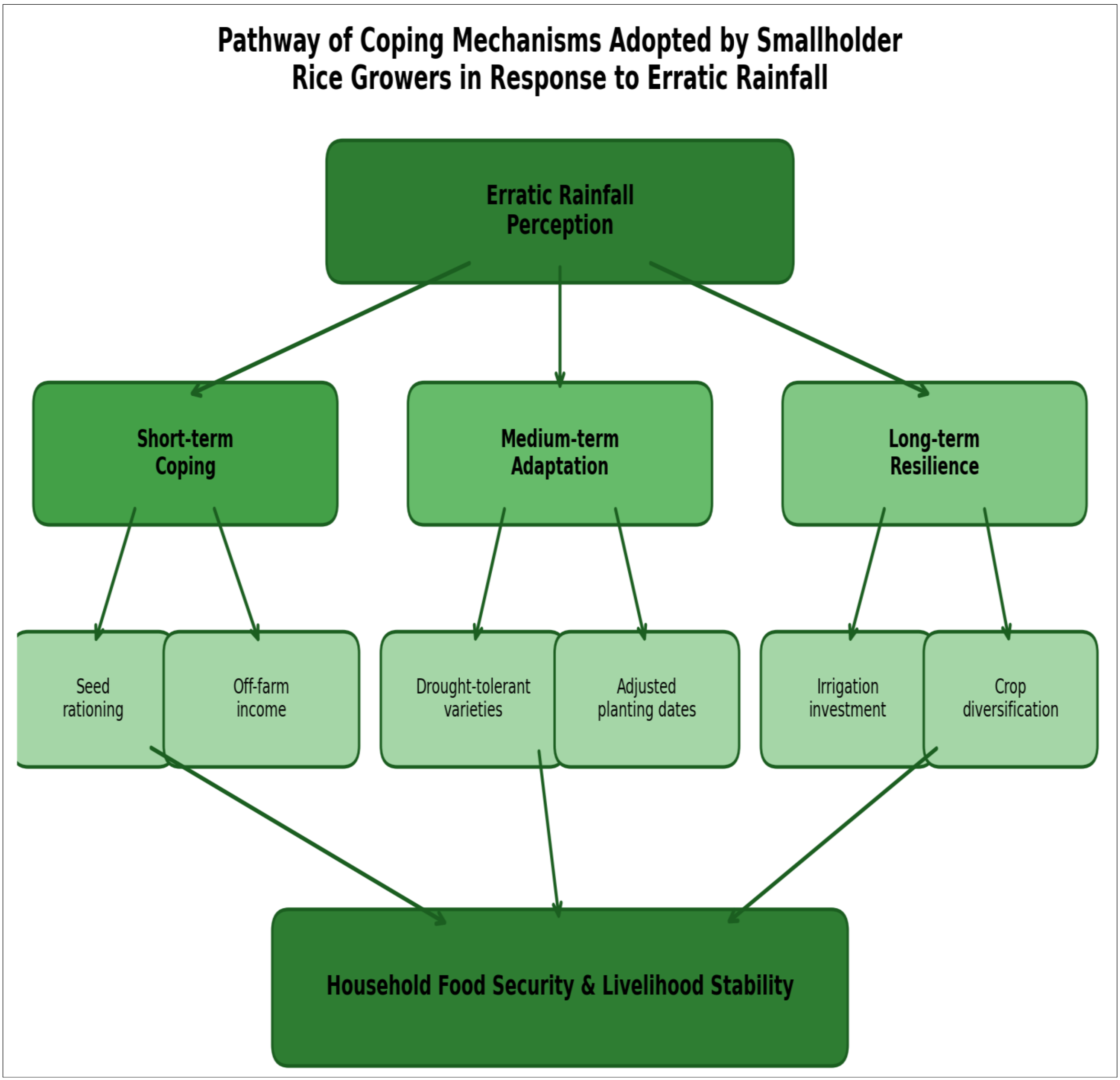

Fig 2: Pathway of coping mechanisms adopted by smallholder rice growers in response to erratic rainfall perception.

Figure 3 presents the correlation heatmap between six socioeconomic factors and the adoption rates of six individual coping strategies. Extension contact showed the strongest positive association with drought-tolerant variety adoption (r = 0.61, *p*<0.001), while farm size correlated most strongly with irrigation investment (r = 0.68, *p*<0.001).

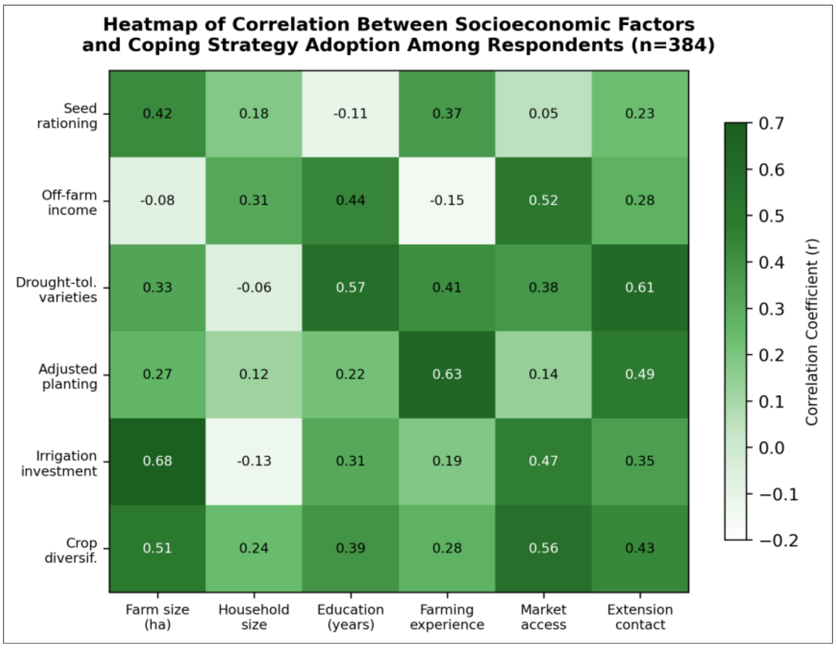

Fig 3: Heatmap of Pearson correlation coefficients between socioeconomic factors and coping strategy adoption among respondents (n = 384)

Comprehensive interpretation

Binary logistic regression confirmed that farming experience (OR = 1.14, 95% CI: 1.04-1.26, p = 0.008), extension service access (OR = 2.37, 95% CI: 1.62-3.47, $p<0.001$), and proximity to market centres (OR = 1.82, 95% CI: 1.16-2.86, p = 0.011) were significant predictors of multi-strategy adoption. The Hosmer-Lemeshow test indicated adequate model fit ($\chi2 = 6.41$, df = 8, p = 0.601), and the Nagelkerke pseudo-R^2 was 0.34. Household size (OR = 1.06, p = 0.412) and gender of household head (OR = 0.87, p = 0.539) did not reach significance. Respondents who perceived rainfall decrease as the dominant change were 1.9 times more likely to adopt medium-term adaptations than those perceiving shifted onset alone, even after adjusting for education and farm size. Qualitative data reinforced this pattern: focus group participants in Bahi district repeatedly linked their decision to seek drought-tolerant seed to an awareness that "rains simply bring less water than they did ten years ago," whereas farmers emphasising onset shifts tended to adjust planting calendars without changing variety choice.

Discussion

The main findings of this research indicate that an overwhelming majority of smallholder rice growers in semi-arid central Tanzania perceive meaningful changes in rainfall patterns, and that the type of change perceived shapes the coping response selected. Nearly 93% of respondents reported at least one perceived shift, with decreased total rainfall, shifted onset, and increased dry spells constituting the three dominant categories. Coping strategies were unevenly distributed across the temporal spectrum, with reactive short-term measures far more prevalent than capital-intensive long-term adaptations.

These perception rates are broadly consistent with observations from comparable agro-ecological zones. Findings from Malawi's Shire Valley showed 89% of maize-legume farmers recognising altered rainfall timing [16], while a Kenyan assessment among irrigated rice growers reported 91% awareness of increased seasonal unpredictability [17]. The convergence across settings suggests that prolonged rainfall variability produces a near-universal cognitive signal among farming communities, irrespective of crop type.

Where the present results part company with earlier work is in the relatively low uptake of long-term resilience strategies. A comparable investigation in the Mekong Delta found that 42% of rice households had invested in water-harvesting infrastructure, roughly double the proportion recorded here [18]. The discrepancy likely reflects differences in access to credit and public infrastructure: Vietnamese farmers benefit from a dense network of cooperatives and subsidised pump schemes, whereas growers in Dodoma Region operate with minimal institutional scaffolding and must self-finance irrigation equipment at prevailing market prices.

Several explanations can account for the strong predictive power of extension contact. Extension officers serve as conduits for new variety information, planting advisories, and weather forecasts; their influence may be amplified in settings where formal education levels are modest and print media reach is limited. The odds ratio of 2.37 suggests that each additional unit of extension contact frequency more than doubles the likelihood of adopting three or more strategies, a finding with clear programmatic relevance. Market proximity likely functions through a different channel: growers closer to trading centres can monetise surplus grain more easily, generating the cash reserves needed for input purchases and small-scale investments [4].

At a broader level, the temporal gradient observed in coping behaviour aligns with the Sustainable Livelihood Framework, which predicts that asset-poor households default to consumption-smoothing tactics while asset-endowed households can absorb short-term losses and invest in structural transformation. The pathway analysis confirms this gradient and highlights extension and market access as the two leverage points most amenable to policy intervention. Strengthening these channels could shift the coping distribution toward more anticipatory and resiliencebuilding strategies, thereby reducing the proportion of households trapped in reactive mode.

Limitations

Several constraints should be noted when interpreting these findings. First, the cross-sectional design captures coping behaviour and perception at a single point, without tracking how either variable evolves across seasons. Longitudinal panel data would enable causal inference about whether perception accuracy drives strategy change or vice versa. Second, rainfall perception was self-reported and not validated against daily station records; although 92.8% of respondents perceived change, the direction and magnitude of perceived shifts may not align perfectly with meteorological data. Third, the sample was confined to two districts in Dodoma Region, and semi-arid rice systems elsewhere in East Africa such as those in northern Kenya or south-western Uganda may exhibit different coping profiles owing to distinct institutional landscapes. Fourth, social desirability bias could inflate reported adoption rates if respondents viewed certain strategies as normatively approved. Finally, the binary coding of multi-strategy adoption (three or more) is somewhat arbitrary; alternative thresholds might yield different predictor rankings.

Conclusion

The main contribution of this research lies in demonstrating that farmer perception of rainfall change is not monolithic but disaggregates into distinct categories decreased total amount, shifted onset, increased dry spells, and unpredictable patterns each carrying different implications for the type of coping response selected. Rather than treating perception as a binary variable (change vs. no change), future extension programming and adaptation planning should map the specific perceptual profile of target communities and tailor advisory messages accordingly.

Supporting evidence from the survey of 384 smallholder rice households in Dodoma Region confirms that short-term reactive measures dominate the coping landscape, adopted by over 60% of growers, while long-term resilience investments remain the preserve of a small, better-resourced minority. The regression model identified extension contact, farming experience, and market proximity as the three significant drivers of diversified coping portfolios, together explaining roughly 34% of the variance in multi-strategy adoption. Qualitative narratives reinforced these statistical patterns, with focus group participants consistently linking variety switching to extension advice and irrigation investment to availability of affordable equipment at nearby market towns.

For the field of climate-adaptation research in semi-arid agricultural settings, these findings carry two-fold significance. First, they fill a geographic and crop-specific gap: prior Tanzanian adaptation research concentrated on maize systems in the southern highlands, leaving rain-fed rice belts in the central plateau largely undocumented. Second, the pathway analysis offers a testable conceptual model linking perception to behaviour to outcomes, which can be applied or challenged in analogous settings across the Sahel, the Horn of Africa, or South Asian monsoon margins.

Several questions remain open for future investigation. Does perception accuracy defined as the correspondence between farmer-reported trends and meteorological station records moderate the effectiveness of coping strategies over multiple seasons? How do gender-differentiated perception profiles influence household-level adaptation decisions when male and female household members disagree on the nature of rainfall change? What role can digital weather information services, delivered via mobile phone, play in correcting perceptual inaccuracies and accelerating the transition from reactive to anticipatory strategies? And at what threshold of extension staffing intensity does the marginal return on multi-strategy adoption begin to plateau? Addressing these questions through panel designs, randomised information experiments, and cost-effectiveness analyses would deepen understanding and sharpen policy recommendations for the millions of rain-dependent rice growers navigating an increasingly uncertain climate.

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