Discover Sustainability

https://doi.org/10.1007/s43621-026-03484-3

Article in Press

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Received: 11 October 2025

Accepted: 6 May 2026

Published online: 24 May 2026

Cite this article as: Kanyiru M.W., Mkindi A.G. & Meya A.I. Potentials of climate smart agriculture in sustaining farming systems through farmer's awareness and rainwater harvesting technologies in northern Tanzania. *Discov Sustain* (2026). https://doi.org/10.1007/s43621-026-03484-3

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Potentials of climate smart agriculture in sustaining farming systems through farmer's awareness and rainwater harvesting technologies in northern Tanzania

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Abstract: This study assessed farmers' awareness (knowledge), use (actual implementation), and perceived effectiveness of rainwater harvesting (RWH) and soil moisture conservation (SMC) techniques for maize production in the sloping highlands of Babati District, Tanzania. A mixed-methods cross-sectional design was employed, combining household surveys (n = 147), focus group discussions (FGDs), and field observations in Dareda Kati and Gajal villages in the Babati District to generate both quantitative and qualitative data. Results indicate a clear gap between awareness and use of RWH and SMC techniques. While 67.35% of respondents were aware of general stormwater management practices, awareness and use of swales and berms (fanya chini) for RWH was extremely low. Only 2.9% of the users reported using swales and berms. In contrast, contour bunds (fanya juu) had a highest usage rate (60.0%), reflecting its long-standing promotion through extension programs. Statistical analysis showed no significant differences in awareness levels between the surveyed villages, suggesting that location alone does not explain variations in technology uptake. Farmers' perceptions further revealed limited understanding of the construction and management of less familiar RWH techniques, even among the few adopters. These findings demonstrate that awareness does not necessarily translate into use and that knowledge depth and practical skills are critical for adoption of RWH and SMC on sloping landscapes. For policy and extension, the results highlight the need for targeted, hands-on training, participatory demonstrations, and strengthened extension support to improve both informed use and correct implementation of low-cost RWH and SMC techniques for resilient maize production under climate variability.

Key words: *Fanya juu, rain water harvesting, soil moisture conservation, farmers' awareness*

1. Introduction

Climate change continues to threaten agricultural productivity in sub-Saharan Africa (SSA), where increased rainfall variability, recurrent droughts, floods, and rising temperatures reduce crop yields and exacerbate food insecurity (1, 2). Maize, the region's staple crop, is cultivated on approximately 27 million hectares; yet average yields remain around 1 t ha^{-1}, far below attainable yields of up to 5 t ha^{-1} under improved management (1). The heavy reliance on rain-fed systems makes smallholder farmers particularly vulnerable to rainfall variability and intra-seasonal dry spells. In northern Tanzania's Babati highlands, annual rainfall ranges between 800 and 1000 mm, generally adequate for maize production (3). However, steep slopes, land degradation, and intense rainfall events contribute to substantial surface runoff, limiting effective rainwater use. Previous studies in Babati and similar highland systems have documented soil erosion, runoff challenges, and the importance of soil and water conservation practices. More broadly, only 15-30% of seasonal rainfall may contribute to crop biomass production due to runoff and evaporation losses (4), underscoring the importance of in-situ rainwater management even in relatively high-rainfall environments. Despite Babati's favorable rainfall totals, efficient rainwater utilization remains constrained by landscape characteristics and management practices.

Rainwater harvesting (RWH) and soil moisture conservation (SMC) practices, including contour bunds (fanya juu), conservation tillage, mulching, and check dams, have demonstrated measurable benefits in reducing runoff and improving soil moisture (4, 5, 6, 7). In Babati, earlier research has primarily emphasized conventional soil conservation measures and general land management practices (8). However, limited attention has been given to the awareness, adoption dynamics, and perceived effectiveness of a broader suite of RWH technologies, particularly swales and berms (fanya chini). Swales and berms are designed to slow runoff and enhance infiltration along contour lines (9), yet their agricultural performance and diffusion within smallholder maize systems in SSA remain underexplored. While engineering studies report that swales can reduce runoff by up to 88% (10, 11), much of this evidence derives from urban stormwater contexts, with minimal empirical assessment in rain-fed smallholder farming systems. Thus, although soil and water conservation challenges in Babati have been documented, there remains a gap in understanding (i) the extent of farmer awareness and use of different in-situ RWH/SMC options, (ii) the determinants of adoption in a high-rainfall yet runoff-prone highland setting, and (iii) why technically suitable interventions such as swales and berms remain largely absent. Addressing these gaps is essential for moving beyond descriptive accounts of erosion challenges toward actionable strategies for improving rainfall utilization.

Previous research on agricultural technology adoption has increasingly employed mixed-methods approaches, combining quantitative surveys with qualitative tools such as focus group discussions and key informant interviews (11, 12). Such designs enable the integration of statistical analysis of adoption patterns with contextual understanding of social and institutional drivers. Building on this body of work, the present study contributes novel empirical evidence from the Babati highlands by systematically assessing farmers' awareness, use, and determinants of RWH/SMC practices, with a specific focus on swales and berms as a potentially suitable yet underutilized technology for sloping maize fields. Unlike prior studies that primarily described conservation challenges or specific practices in isolation, this study integrates quantitative adoption analysis with qualitative insights to identify knowledge gaps and village-level contextual differences influencing technology uptake.

The specific objectives are to: a. Quantify farmers' awareness and use of different in-situ RWH and SMC techniques.

b. Compare awareness, use, and perceived effectiveness of these techniques between villages. c. Examine determinants of adoption using multivariable analysis.

d. Identify barriers and knowledge gaps regarding swales and berms on sloping maize lands. By clarifying adoption dynamics in a high-rainfall yet runoff-constrained environment, this study provides evidence-based guidance for targeted extension strategies aimed at improving in-situ rainwater management and strengthening maize system resilience under climate variability.

2. Conceptual Framework

This study is guided by a conceptual framework that links climatic, biophysical, and socio-institutional factors to the adoption of RWH and SMC technologies in smallholder maize systems (13). Rainfall variability, slope, and runoff dynamics influence soil moisture availability in sloping fields (14, 15, 16), while farmer awareness, extension support, perceptions, and resource capacity shape the adoption of technologies such as fanya juu (17), fanya chini etc., the adoption and effectiveness of these practices are expected to enhance soil moisture retention, which ultimately affects maize productivity.

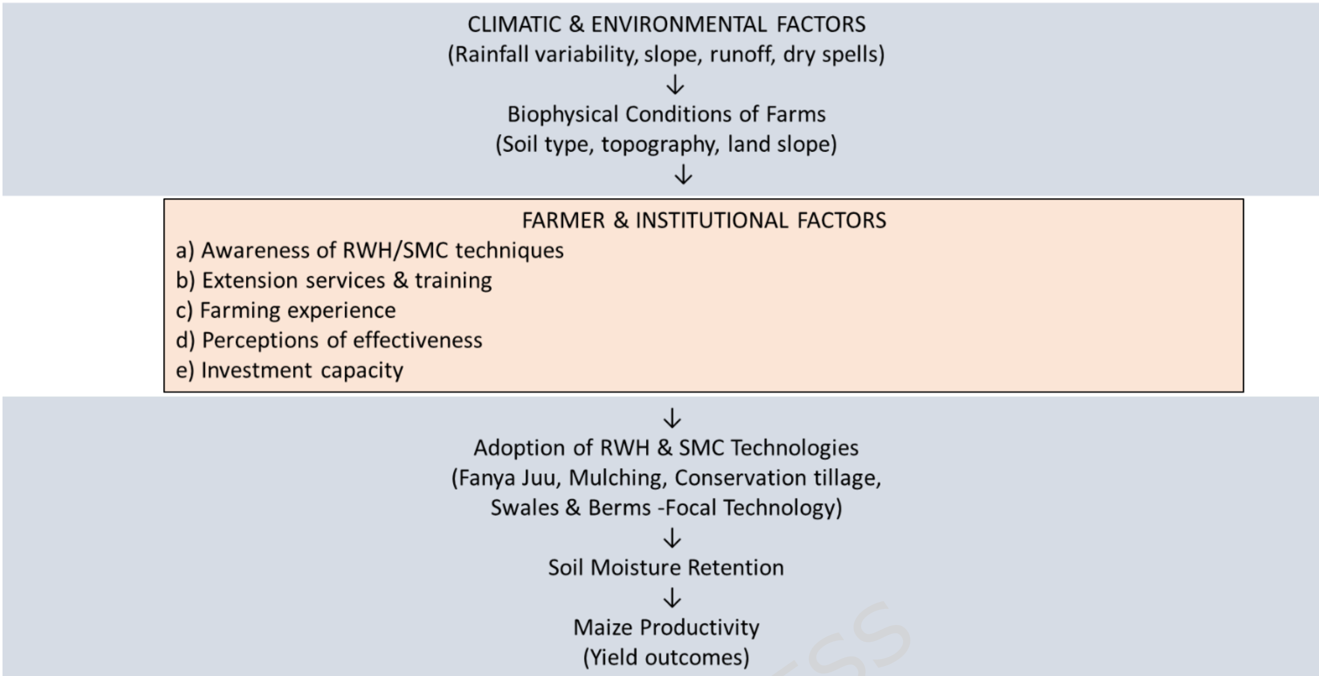

Figure 1: Conceptual framework illustrating the relationships between climatic conditions, farmer awareness, adoption of rainwater harvesting and soil moisture conservation technologies (including swales and berms), and maize productivity in sloping highland farming systems. Source: Authors' field survey data (2025).

3. Materials and Methods

3.1 Description of the Study Site

The study was conducted in Dareda Kati and Gajal villages in Ayalagaya Ward, Babati District Council, Manyara Region, northern Tanzania. Babati District lies between latitudes 3°-5° S and longitudes 35°-37° E within the Great Rift Valley and is characterized by undulating highlands, rolling hills, and mountainous terrain with elevations ranging from 950 to 2,450 m above sea level (18). The sampled maize fields are predominantly located on sloping landscapes, where moderate to steep gradients enhance surface runoff and soil erosion, particularly during intense rainfall events. Such topographic conditions directly influence soil moisture retention and the effectiveness of in-situ rainwater harvesting technologies (RWHTs).

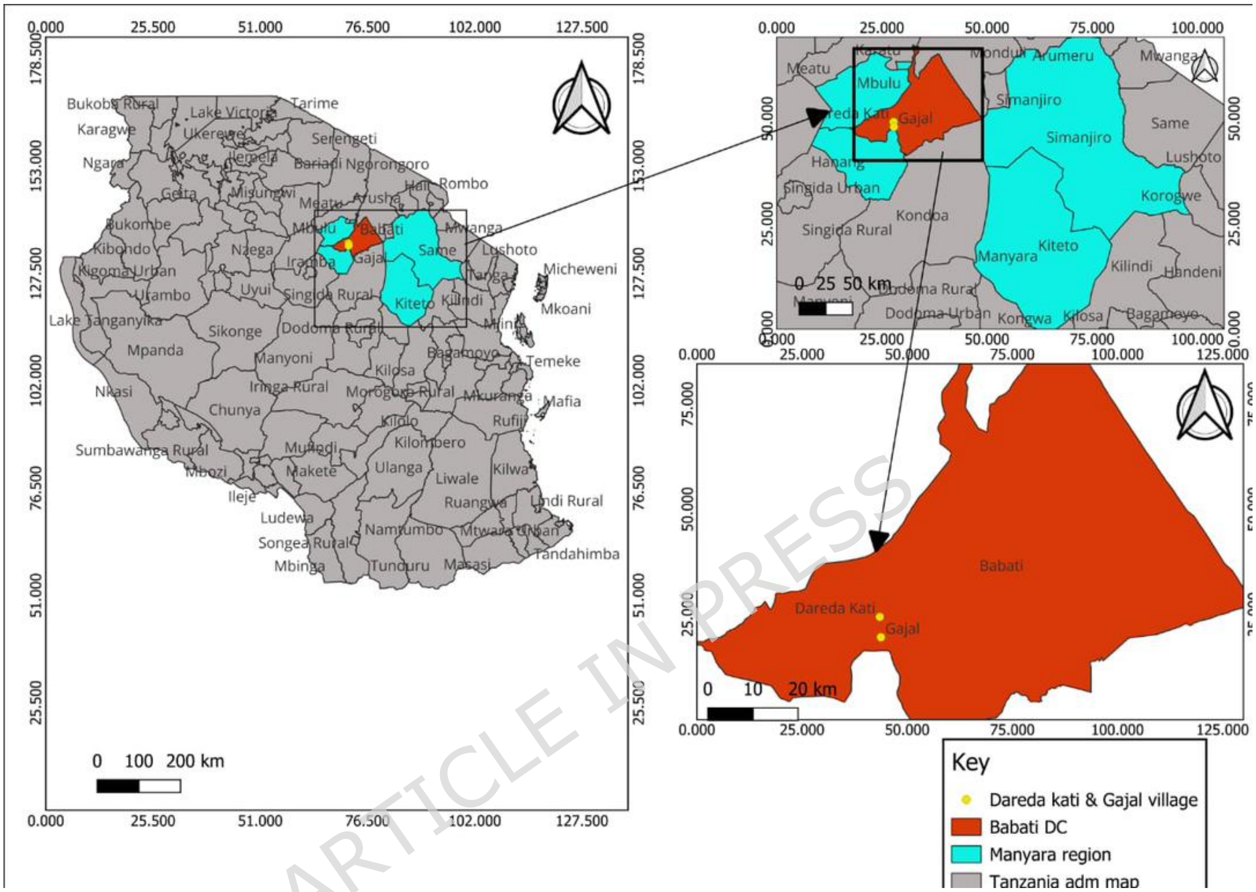

Figure 2: Location of Dareda Kati and Gajal villages in Ayalagaya Ward, Babati District, Manyara Region, northern Tanzania. The map shows the administrative boundaries and the position of the study villages within the district. Source: Authors' compilation based on administrative boundary data and GIS analysis (2025).

Rainfall in the study area follows a bimodal pattern, with short rains occurring from October to December and long rains from February to May. The highland zones receive approximately 800-1000 mm of annual rainfall, with mean temperatures ranging from 10°C to 25°C (3, 19). However, rainfall is not evenly distributed across the growing season. A pronounced dry period occurs from June to September, while peak rainfall is concentrated in March-April and November-December (Figure 2).

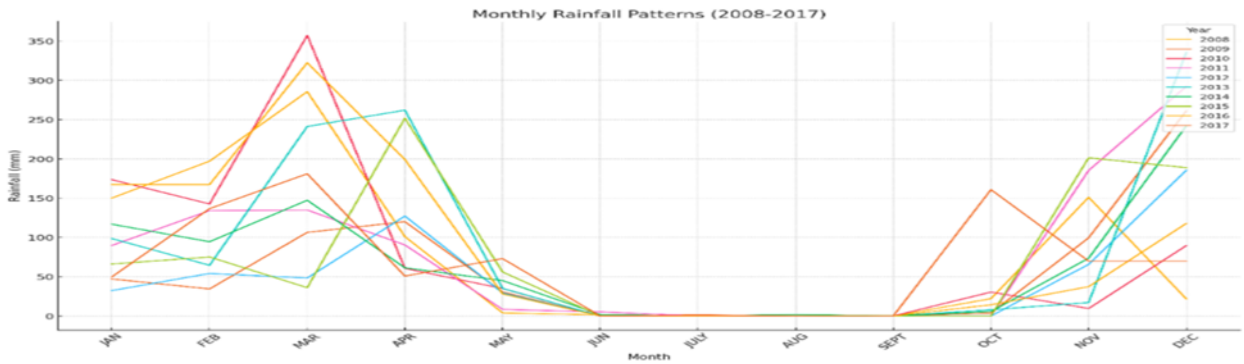

Figure 3: Monthly rainfall distribution in Babati District from 2008 to 2017, illustrating bimodal rainfall peaks and intra-seasonal variability. Source: Babati Meteorological Station (2018).

Analysis of historical rainfall data from Babati Meteorological Station (2008-2018) reveals considerable inter-annual variability, with fluctuations around the long-term average of 800-1000 mm. Monthly records (2008-2017) further indicate irregular rainfall distribution characterized by episodic high-intensity storms followed by intra-seasonal dry spells. Under sloping field conditions, such rainfall patterns increase runoff generation and reduce effective infiltration, leading to sub-optimal soil moisture availability for maize production despite adequate total annual rainfall. These hydro-climatic dynamics underscore the relevance of in-situ rainwater harvesting and soil moisture conservation measures, particularly contour-based practices such as contour bunds (fanya juu) and swales and berms (fanya chini), which are designed to slow runoff and enhance water infiltration.

Soils in the study area are predominantly red sandy loams, grey sandy loams, and red clay loams, which are moderately fertile and suitable for cereal-legume systems (19). Agriculture is the primary livelihood activity, with smallholder farmers mainly practicing rain-fed maize cultivation intercropped with beans, pigeon peas, and sunflower (3). Given the combination of sloping terrain, variable rainfall, and reliance on rain-fed maize production, the study area provides a suitable context for assessing farmers' awareness and use of rainwater harvesting and soil moisture conservation technologies.

3.2 Definition of Terms

In this study, RWH refers to in-situ practices designed to capture, slow, and enhance infiltration of rainfall or surface runoff within the field. SMC, also referred to as soil moisture retention (SMR), refers to practices that reduce evaporation losses and maintain soil water within the root zone for improved crop uptake. While conceptually distinct, several practices serve both functions simultaneously by reducing runoff and improving infiltration while also enhancing soil water retention. For analytical clarity, practices were categorized according to their primary functional objective, although some techniques are recognized as contributing to both RWH and SMC processes.

Table 1. Classification of rainwater harvesting and soil moisture conservation practices. Source: Authors' field survey data (2025).

Practice	**Primary Classification**	**Functional Role**
Contour Bunds (Fanya juu)	RWH & SMC	Reduces runoff, controls erosion, enhances infiltration
Swales and berms (Fanya chini)	RWH & SMC	Captures runoff along contour, increases infiltration and soil moisture
Kinga Maji (Water diversion structures)	RWH	Redirects surface runoff to reduce erosion
Supplementary irrigation	RWH	Applies harvested water to crops during dry periods

Practice	Primary Classification	Functional Role
Mulching	SMC	Reduces evaporation, improves soil moisture retention
Minimum tillage	SMC	Improves soil structure and water retention
Cover cropping	SMC	Enhances soil cover, reduces evaporation and erosion
Use of manure/Organic inputs	SMC	Improves soil organic matter and water-holding capacity

3.3 Study Design

A mixed-methods approach (surveys, focus group discussions, and field observations) was used to capture both quantitative adoption patterns and qualitative insights on barriers, perceptions, and implementation practices. A semi-structured questionnaire comprising both closed and open-ended questions was developed and pre-tested to refine question wording and estimate the time required for administration. The questionnaire has been deposited in the Zenodo repository and is available at: https://doi.org/10.5281/zenodo.19229456. The questionnaire variables were organized into four major categories to enhance analytical clarity: (i) socio-demographic characteristics, (ii) farm characteristics, (iii) awareness and use of rainwater harvesting (RWH) and soil moisture conservation (SMC) practices, and (iv) farmer perceptions and constraints. In the same upload, there is a section (Section E), containing the guide for Focus Group Discussion (FGD) with Key Informants and also a guide for field observations.

3.4 Sample Size Determination

To determine the required survey sample size, a priori power analysis was conducted using G*Power 3.1. The calculation was based on a two-sample comparison between villages (Dareda Kati vs. Gajal), reflecting the study's objective of examining inter-village differences in awareness and use of RWH and SMC practices (20). A small effect size (Cohen's d = 0.233) was selected to reflect the expectation of modest differences between villages in adoption-related outcomes, consistent with prior smallholder technology adoption studies in similar contexts. The analysis assumed a significance level (α) of 0.05, statistical power of 0.80, and equal allocation (1:1) between villages. Under these assumptions, a minimum total sample of 147 respondents was required. Although the primary power calculation was based on a two-sample comparison framework, the final sample size was also sufficient for subsequent logistic regression analyses examining determinants of awareness and adoption, ensuring adequate statistical reliability for both comparative and multivariable analyses.

3.5 Data Collection

The study was conducted in two purposively selected villages; Dareda Kati and Gajal in Babati District, northern Tanzania (21). The villages were selected based on their prominence in maize production, sloping topography, and reported runoff challenges, making them suitable contexts for assessing RWH and SMC practices. According to village administrative records and consultation with local agricultural officers, both villages are dominated by smallholder maize-farming households. All maize farmers aged 18 years and above were considered eligible for participation.

Data collection was conducted between March and April 2025 through face-to-face interviews with 147 purposively selected smallholder farmers from Dareda Kati and Gajal villages. Each farmer was interviewed individually to ensure independence of responses, and each interview lasted approximately 10 minutes. The questionnaire was originally developed in English and administered using an interviewer-assisted approach. During data collection, the research team, consisting of the principal researcher and three trained enumerators, operated in pairs. In each pair, one member administered the questionnaire by reading and translating the questions orally into Swahili to ensure clarity and comprehension, while the other recorded the responses provided by the farmer. All enumerators received prior training to ensure consistency in translation and data recording procedures. Upon completion of fieldwork, the collected data were reviewed, cleaned, and subsequently analyzed using appropriate statistical and qualitative analysis techniques.

Participants recruitment was facilitated through collaboration with village leaders and ward-level agricultural extension officers (22). A community meeting was scheduled on a non-market weekday afternoon at the agricultural office compound in each village to maximize attendance and minimize interference with farming activities. All maize farmers were invited through village announcements, ensuring open participation rather than selective nomination (23, 24). During the meeting, the research team introduced the study objectives and procedures in both English and Kiswahili, and informed consent was obtained from all willing participants.

Within each village, simple random sampling was then applied among meeting attendees using folded papers labeled “Today,” “Tomorrow,” and blank to allocate survey participation. In Dareda Kati, 75 farmers were selected for the interviewer-administered survey and 5 participants (community elders and extension officers) were selected for one focus group discussion (FGD). In Gajal, 72 farmers were selected for the survey and 5 (community elders and ward extension officers) for 1 FGD using the same procedure. FGDs captured expert and community-level insights. In general, 2 Focus Group Discussions (FGDs) were held with 10 key informants (community leaders, and agricultural extension officers) purposively selected from the two villages to gather in-depth insights on group-level practices, historical changes, and perceived barriers to technologies adoption. A group size of five participants per village was considered adequate for FGDs, as the discussions aimed to capture informed expert perspectives rather than statistical representation, and sessions were continued until no new substantial insights emerged, indicating adequacy of information (saturation).

Because village selection was purposive and participation was limited to farmers who attended the community meeting, the sample should be interpreted as context-specific rather than statistically representative of all maize farmers in Babati District. While random allocation was used among attendees, farmers who did not attend the meeting may differ systematically from participants. Therefore, findings provide analytical insights into adoption patterns within the selected villages but should not be generalized to the wider district without caution. In addition, selected participants' farms were visited for direct field observations to verify the presence of practices such as swales and berms, and other land management features.

Direct field observations (on the evidence of use of RWH and SMC practices, topographical characteristics of the area and general land management practices) complemented other data sources, enhancing the overall quality of the dataset. Descriptive variables such as village, farming experience, and farm size were used to characterize respondents, while awareness, perceptions, and investment in RWH and SMC were treated as independent variables influencing technology adoption. The primary dependent variables included the use of RWH and SMC techniques, particularly swales and berms, and perceived effectiveness in improving soil moisture and maize productivity. Qualitative data from FGD and field observations were used to contextualize adoption patterns, identify barriers, and validate reported practices.

Table 2. Structured overview of questionnaire variables grouped into socio-demographic characteristics, farm characteristics, rainwater harvesting and soil moisture conservation practices, and farmer perceptions, indicating the

role of each variable as dependent, independent, or descriptive in the analysis. Source: Authors' field survey data (2025).

Category	Data Type	Method	Key Variables Collected	Variable Role in Analysis
Socio-demographic characteristics	Quantitative	Survey (interviewer-administered)	Role in community, village, years of maize farming experience	Descriptive
Farm characteristics	Quantitative	Survey & Observation	Farm size (acres), maize yield (bags), land slope (observed), land management practices	Independent / Descriptive
RWH & SMC practices	Quantitative & Qualitative	Survey, Observation	Awareness of RWH/SMC techniques, use of fanya juu, swales and berms (fanya chini), soil moisture monitoring frequency, investment in RWH/SMC (TZS)	Independent (key predictors)

Category	Data Type	Method	Key Variables Collected	Variable Role in Analysis
Perceptions and effectiveness	Quantitative & Qualitative	Survey & FGDs	Perceived effectiveness of RWH/SMC techniques, importance of soil moisture, most effective yield improvement methods	Independent / Explanatory
Barriers and adoption context	Qualitative	Focus Group Discussions (FGDs)	Barriers to adoption, historical adoption trends, extension support, knowledge gaps on swales and berms	Explanatory (qualitative)
Biophysical observations	Qualitative	Field Observation	Presence of fanya juu structures, swales and berms, topographical characteristics, runoff indicators	Supporting / Validation

Table 3. Field observation checklist for rainwater harvesting and soil moisture conservation technologies. Source: Authors’ field survey data (2025).

Technology	Observation Criteria	Minimum Criteria for Classification as Properly Constructed
Contour bunds (Fanya juu)	Presence of trench and uphill bund; alignment along contour; bund continuity; visible sediment deposition	Continuous bund aligned with contour and evidence of runoff control
Swales and berms (Fanya chini)	Trench aligned along contour; level trench base; excavated soil formed into downhill berm; absence of downslope drainage orientation	Contour alignment + level base + clearly formed downhill berm
Water diversion structures (Kinga maji)	Diversion channel present; direction of water flow controlled; erosion protection structures	Structured diversion aligned to safely redirect runoff
Minimum tillage	Reduced soil disturbance; visible crop residue retention	Minimal soil inversion with retained surface cover
Mulching	Visible organic cover on soil surface	≥ partial surface cover with plant residue or organic matter
Cover cropping	Presence of live cover crop or intercropped legumes/grasses	Intentional vegetative ground cover maintained

3.6 Data Analysis

Prior to analysis, variables were categorized as dependent, independent, and descriptive to ensure consistency between the study objectives, conceptual framework, and statistical interpretation. Quantitative data were entered, cleaned, and analyzed using R software version 4.4.1. Descriptive statistics (means, medians, standard deviations, frequencies) and logistic regression models were used to summarize farm characteristics, awareness levels, and technology use. Inferential analysis included: Pearson's chi-squared tests (to assess relationships between categorical variables, e.g., village vs. awareness), fisher's exact test (when expected cell counts <5), and independent-sample t-tests (to compare continuous variables like maize yield). Qualitative data from FGD were subjected to thematic analysis, where emerging themes related to perceptions, constraints, and recommendations were identified, coded, and integrated into the discussion.

3.7 Ethical Approval

Ethical approval for this study was obtained from KNCHREC, which is a zonal ethics body comprising the Kibong'oto Infectious Diseases Hospital (KIDH), The Nelson Mandela African Institution of Science and Technology (NM-AIST), and the Centre for Educational Development in Health, Arusha (CEDHA); (Approval No: KNCHREC/0002/02/2025, approved on 8th March 2025). Informed consent was obtained from all participants prior to data collection, and participants were assured of confidentiality and anonymity.

4. Results

4.1 Information on Years of Experience in Maize Farming, Field Size and Yield of the Respondents

A total of 147 maize-growing farmers participated in the survey, including 75 respondents from Dareda Kati and 72 from Gajal. All respondents reported prior experience in maize production. Farming experience ranged from 2 to 52 years, with a mean of 21 years (SD = 12.81). Half of the respondents had 20 years or less of experience, while 25% had 10 years or less and 75% had up to 29.50 years. Farmers in Dareda Kati reported slightly higher average experience (22 years) compared to Gajal (19 years).

Farmers reported maize field size in acres, which were converted to hectares (1 acre = 0.41 ha) for standardization and comparability. After conversion, field sizes ranged from 0.20 ha to 3.20 ha, with an overall mean of 0.91 ha (SD = 0.59). Approximately 25% of fields measured 0.40 ha or less, while 75% were 1.20 ha or smaller, indicating predominantly smallholder production systems. Dareda Kati had a slightly larger mean field size (0.97 ha) than Gajal (0.85 ha), although Gajal exhibited greater variability (SD = 0.63) compared to Dareda Kati (SD = 0.55).

Maize yield was self-reported in bags per acre. To standardize reporting, yields were converted to kilograms per hectare (kg/ha). Farmers reported harvested maize in standard 100 kg bags. Reported production was first converted to kilograms by multiplying the number of bags by 100 kg. Field size, originally reported in acres, was converted to hectares prior to calculation. Yield was computed using the following formula:

$$\text{Yield (kg/ha)} = \frac{\text{Number of bags} \times 100\ \text{kg}}{\text{Field size (acres)} \times 0.41}$$

Based on this conversion, maize grain yield ranged from 445 kg/ha to 10,675 kg/ha, with a mean of 3,429 kg/ha and a median of 3,558 kg/ha. The interquartile range indicates that 25% of fields produced 2,224 kg/ha or less, while 75% produced up to 4,448 kg/ha. Average yield was slightly higher in Gajal (3,469 kg/ha) than in Dareda Kati (3,391 kg/ha), with greater variability observed in Gajal (SD = 1,484 kg/ha) relative to Dareda Kati (SD = 1,384 kg/ha). Farmers reported yields for dried grain under typical local storage conditions; no independent adjustment for moisture content was applied.

To ensure internal consistency, reported harvest quantities (bags) and field sizes (acres) were cross-checked during interviews. All unit conversions (acres to hectares and bags to kilograms) were verified during data entry. Implausible combinations of area and production were reviewed and corrected where necessary. Descriptive screening was conducted to identify extreme outliers prior to analysis. Although yield data were self-reported and may be subject to recall bias, these validation procedures were implemented to minimize measurement and conversion errors.

Table 4: An overview of farmers' years of experience, maize field size and grain yield (N = 147). Source: Authors' field survey data (2025).

Variable	Village	Mean	SD
Years of experience	**All Villages**	20.91	12.81
	Dareda Kati	22.40	13.30
	Gajal	19.40	12.20
Maize field size (ha)	**All Villages**	0.91	0.59
	Dareda Kati	0.97	0.55
	Gajal	0.85	0.63
Maize grain yield (kg/ha)	**All Villages**	3429	1429
	Dareda Kati	3391	1384
	Gajal	3469	1484

4.2 Awareness of in-Situ Rainwater Harvesting and Soil Moisture Conservation Techniques

Overall, 99 out of 147 farmers (67.35%) reported being aware of RWH technologies, while 48 farmers (32.65%) reported no awareness. At the village level, awareness was 64.0% (48/75) in Dareda Kati and 70.83% (51/72) in Gajal, representing a difference of 6.83 percentage points in favor of Gajal. A Pearson's chi-squared test with Yates' continuity correction was conducted to examine whether awareness differed by village. The association was not statistically significant ($\chi^2 = 0.50$, df = 1, $p = 0.48$). The estimated difference in awareness between villages was 6.83 percentage points (95% CI: approximately -8% to 22%), indicating considerable uncertainty around the true magnitude of the difference. While the statistical test does not provide evidence of a significant association between village and awareness, the confidence interval suggests that both small negative and moderate positive differences remain plausible. These findings indicate broadly comparable levels of awareness between the two villages, although modest differences cannot be ruled out.

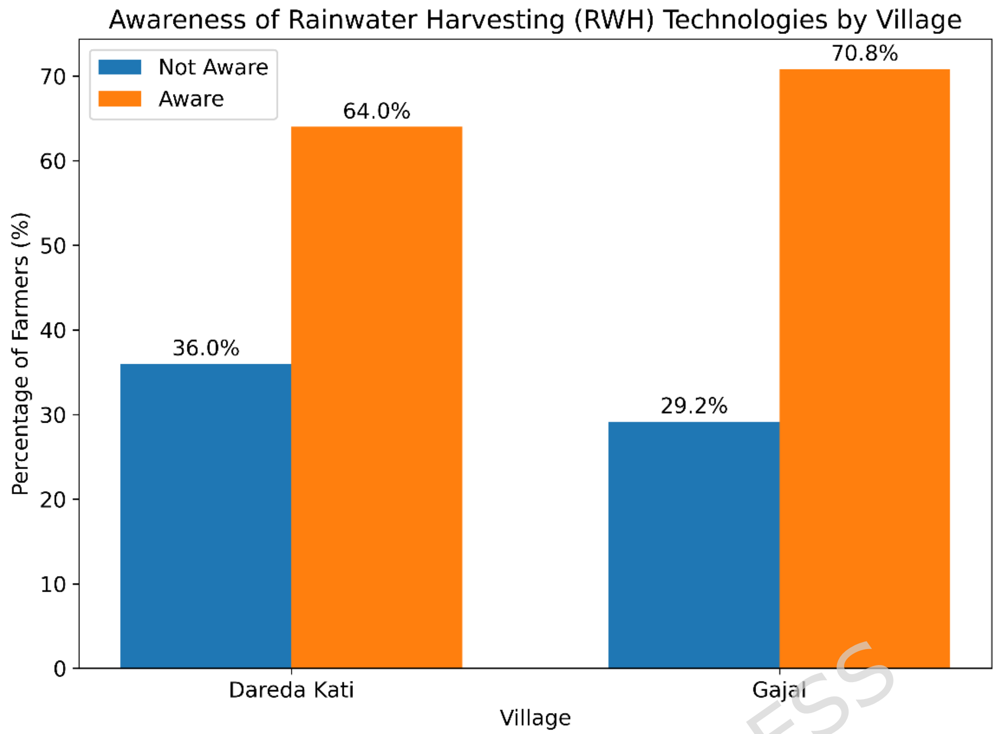

Figure 4. Percentage of farmers aware and not aware of rainwater harvesting technologies in Dareda Kati (n = 75) and Gajal (n = 72), Babati District, northern Tanzania. Awareness levels were broadly comparable between villages, with slightly higher reported awareness in Gajal. Source: Authors' field survey data (2025)

4.3 Rainwater Harvesting and Soil Moisture Conservation Techniques Used by Maize Growing Farmers

Out of the 147 surveyed farmers, 105 (71.4%) reported using at least one RWH/ or SMC practice, while 42 farmers (28.6%) did not use any technique. Among users (N = 105), *fanya juu* was the most widely implemented practice, reported by 63 farmers (60.0%). Supplementary irrigation (26 farmers; 24.8%) and mulching (24 farmers; 22.9%) were also commonly practiced, mainly to address delayed rainfall onset and intra-seasonal dry spells. Usage of other techniques was limited: *kinga maji* (5 farmers; 4.8%), minimum tillage (4 farmers; 3.8%), swales and berms (3 farmers; 2.9%), and cover cropping (3 farmers; 2.9%). Because multiple responses were allowed, percentages exceed 100%.

At the village level, clear differences in implementation were observed. In Dareda Kati (n = 75), *fanya juu* was the dominant practice (38 farmers), while fewer farmers reported using supplementary irrigation (8), mulching (7), *kinga maji* (4), minimum tillage (2), and swales and berms (2). No farmers reported the use of cover cropping in this village. In contrast, Gajal (n = 72) showed relatively more diversified adoption. Although *fanya juu* remained the most common practice (25 farmers), higher numbers were recorded for supplementary irrigation (18 farmers) and mulching (17 farmers) compared to Dareda Kati. Limited uptake was observed for *kinga maji* (1), minimum tillage (2), swales and berms (1), and cover cropping (3). These findings indicate that while *fanya juu* dominate in both villages, Gajal farmers demonstrate relatively greater use of moisture-retention and supplementary water management practices. Figure 5 illustrates the village-wise distribution of RWH and SMC techniques.

Table 5. Frequency and percentage of farmers using at least one rainwater harvesting and soil moisture conservation practice (N = 105). Multiple responses were allowed; percentages therefore do not sum to 100%. Source: Authors' field survey data (2025).

Technique	**Number of Farmers**	**% of Users (N = 105)**
Contour bunds (fanya juu)	63	60.0
Supplementary irrigation	26	24.8
Mulching	24	22.9
Kinga maji	5	4.8
Minimum tillage	4	3.8

Technique	Number of Farmers	% of Users (N = 105)
Swales and berms (fanya chini)	3	2.9
Cover cropping	3	2.9

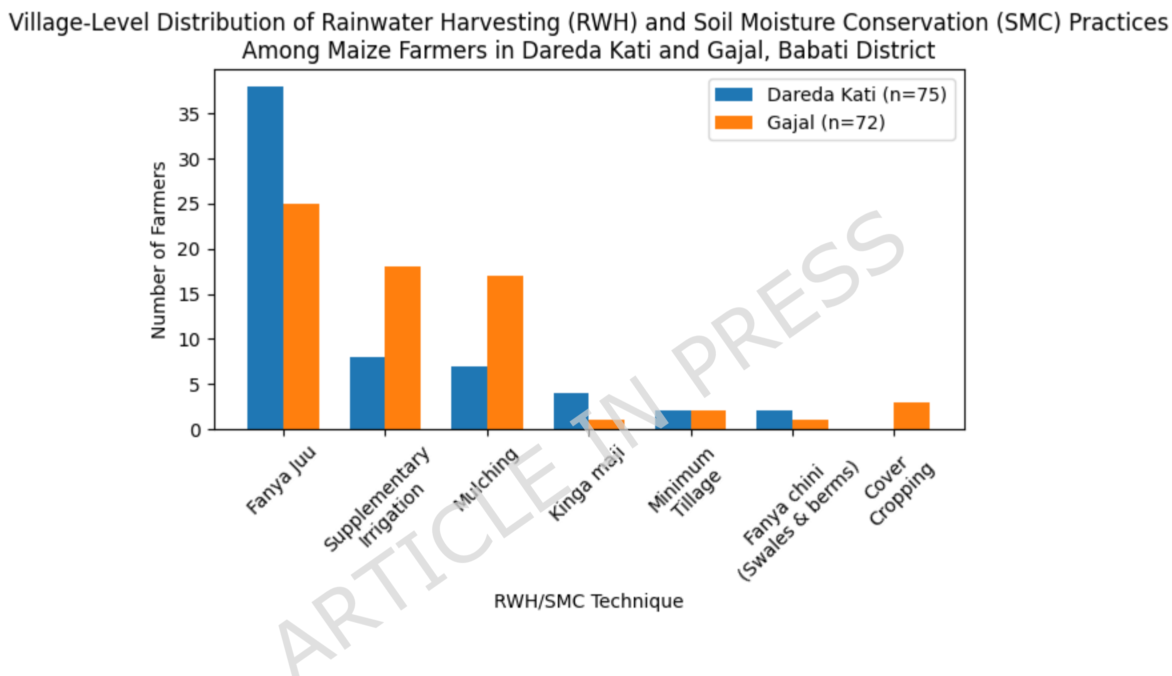

Figure 5. Village-level distribution of rainwater harvesting and soil moisture conservation practices among maize farmers in Dareda Kati (n = 75) and Gajal (n = 72), Babati District, northern Tanzania. Source: Authors' field survey data (2025).

4.4 Comparative Perceptions of Techniques' Effectiveness

Perceived effectiveness was evaluated only among farmers who reported using each respective technology to ensure comparable denominators and avoid conflating awareness with performance assessment. Among fanya juu users, perceptions were overwhelmingly positive in both villages. In Dareda

Kati (n = 38), half of the users (50.0%) rated the practice as very effective, 42.1% as effective, and 7.9% as neutral. In Gajal (n = 25), perceptions were even more favorable, with 76.0% rating it very effective and 24.0% effective. No respondents rated the practice as ineffective in either village, reinforcing its strong perceived performance in runoff and erosion control. For supplementary irrigation, positive perceptions were also evident, though slightly stronger in Gajal. In Dareda Kati (n = 8), 75.0% rated it effective, while 12.5% each rated it neutral and very effective. In Gajal (n = 18), 61.1% rated it effective and 38.9% very effective, with no neutral responses. Mulching was similarly well regarded. In Dareda Kati (n = 7), 71.4% rated it effective, 14.3% very effective, and 14.3% neutral. In Gajal (n = 17), evaluations were evenly split between effective (47.1%) and very effective (47.1%), with only 5.9% neutral. Low-frequency practices ($n \leq 4$ per village), including kinga maji, minimum tillage, cover cropping, and swales and berms, were not interpreted due to limited sample sizes. Overall, perceived effectiveness closely aligns with usage patterns. Widely used practices particularly fanya juu and supplementary irrigation received consistently strong evaluations, suggesting that farmer uptake is reinforced by positive experiential outcomes.

Table 6. Perceived effectiveness of rainwater harvesting and soil moisture conservation practices among users. Source: Authors’ field survey data (2025).

Village	Technique	Users (n)	Effective (%)	Neutral (%)	Very Effective (%)
Dareda Kati	Fanya juu	38	42.1	7.9	50.0
Gajal	Fanya juu	25	24.0	0.0	76.0
Dareda Kati	Supplementary irrigation	8	75.0	12.5	12.5

Village	**Technique**	**Users (n)**	**Effective (%)**	**Neutral (%)**	**Very Effective (%)**
Gajal	Supplementary irrigation	18	61.1	0.0	38.9
Dareda Kati	Mulching	7	71.4	14.3	14.3
Gajal	Mulching	17	47.1	5.9	47.1

4.5 Logistic Regression Models.

A multivariable logistic regression model was fitted to examine determinants of awareness of RWHTs. The model included maize farming experience, farm size, village, and knowledge of soil and water conservation techniques as predictors ($n = 143$). Results indicated that knowledge of conservation techniques was significantly associated with awareness of RWHT ($\beta = 1.01$, $p = 0.01$). Farmers who reported knowledge of at least one technique were approximately 2.75 times more likely to be aware of RWHT compared to those who did not report such knowledge. In contrast, farming experience ($p = 0.47$), farm size ($p = 0.49$), and village ($p = 0.68$) were not statistically significant predictors. The overall model demonstrated modest explanatory power (Pseudo $R^2 = 0.05$) but provides exploratory evidence that knowledge exposure plays a central role in awareness of rainwater harvesting practices.

Also, a logistic regression model was fitted to examine determinants of swales and berms use. However, the model did not converge due to quasi-complete separation, indicating that very few farmers reported using swales and berms. This suggests extremely low adoption levels within the study area, limiting the ability to statistically estimate determinants of use. The near absence of adoption reinforces qualitative findings that swales and berms remain underutilized despite their suitability for sloping terrain.

Lastly, a multivariable logistic regression model was fitted to examine determinants of use of any RWH or SMC technique (n = 147). The model was statistically significant (LLR $p < 0.001$) and demonstrated strong explanatory power (Pseudo $R^2 = 0.569$). Knowledge of conservation techniques was a highly significant predictor of adoption ($\beta = 4.63$, $p < 0.001$), with farmers who reported knowledge being approximately 102 times more likely to use at least one RWH/SMC practice compared to those without such knowledge. Village location was also significant ($\beta = 1.53$, $p = 0.024$), indicating that farmers in Gajal were approximately 4.6 times more likely to adopt RWH/SMC techniques than those in Dareda Kati. In contrast, farming experience and farm size were not statistically significant predictors. These findings highlight the central role of knowledge exposure and local contextual factors in shaping adoption of rainwater harvesting practices.

Table 7. Multivariable Logistic Regression Models for Awareness and Adoption of Rainwater Harvesting and Soil Moisture Conservation Techniques

Model 1: Determinants of Awareness of RWHTs (n = 143)

Variable	**Coefficient (β)**	**Odds Ratio (OR)**	**p-value**	**Significance**
Farming Experience	—	—	0.47	Not significant
Farm Size	—	—	0.49	Not significant
Village	—	—	0.68	Not significant
Knowledge of Conservation Techniques	1.01	2.75	0.01	*
Constant	—	—	—	—

Model statistics:

Pseudo $R^2 = 0.05$

n = 143

Model 2: Determinants of Swales and Berms Use

The logistic regression model did not converge due to quasi-complete separation, indicating extremely low adoption of swales and berms among respondents. Consequently, regression coefficients could not be reliably estimated.

Model 3: Determinants of Use of Any RWH/SMC Technique (n = 147)

Variable	Coefficient (β)	Odds Ratio (OR)	p-value	Significance
Farming Experience	—	—	>0.05	Not significant
Farm Size	—	—	>0.05	Not significant
Village (Gajal vs Dareda Kati)	1.53	4.60	0.024	*
Knowledge of Conservation Techniques	4.63	102.00	<0.001	***
Constant	—	—	—	—

Model statistics:

Pseudo $R^2 = 0.569$

LLR $p < 0.001$

n = 147

4.6 Results from Focus Group Discussions and Field Observations

Findings from the focus group discussions (FGDs), survey responses, and direct field observations were triangulated to enhance the reliability of results regarding the awareness and usage of RWH/SMC technologies. Across FGDs, soil erosion on sloping lands was consistently identified as a major challenge, contributing to nutrient loss, declining soil quality, and lower yields compared to lowland areas. These concerns were consistent with survey results indicating that fanya juu was the most widely practiced RWH/SMC technique in both villages.

Survey data showed relatively high reported usage of fanya juu, particularly among farmers cultivating steep slopes. This pattern was corroborated through field observations, where fanya juu structures were visibly present in several maize fields. observations were conducted on 46 farms to verify reported practices. Fanya juu structures were observed on 35 farms and generally met minimum criteria, including contour alignment and visible sediment retention. In contrast, although one farm displayed a trench resembling a swale, it did not meet the defined criteria (lacking contour alignment and a formed downhill berm). No properly constructed swales and berms were observed. Very few farms showed evidence of kinga maji, minimum tillage, or cover cropping, consistent with survey findings. These observations corroborate survey and FGD results, strengthening triangulation. The structures were generally identifiable by uphill bunds formed from soil excavated from trenches below them. In most cases, bunds followed the contour lines, and sediment accumulation behind the bunds provided visible evidence of runoff reduction and soil retention. Although minor deviations in alignment and trench dimensions were observed, the functionality of these structures in controlling erosion was evident.

In contrast, reported awareness and usage of swales and berms were extremely low in both survey and FGD findings. To avoid overstating usage, there was a distinction between self-reported use and correct technical identification based on defined structural criteria. FGDs revealed that several participants who claimed familiarity with swales frequently confused them with drainage trenches or irrigation channels, as both involve excavation. This misunderstanding was verified during field visits. Although one structure partially resembled a swale and berm (Plate 1), closer inspection showed that it did not meet minimum design criteria, including contour alignment, a level trench base, and formation of a downhill berm. Most trenching observed in fields was oriented downslope to facilitate water drainage rather than along contour lines to enhance infiltration. Consequently, while a small number of farmers reported awareness or/and use, no correctly constructed swales and berms were verified in the field. These findings indicate that self-reported awareness may overestimate functional knowledge and proper implementation, underscoring the importance of distinguishing between nominal recognition and correct technical understanding.

The convergence of survey responses, FGD discussions, and physical verification strengthens confidence in the conclusion that while fanya juu is widely understood and properly implemented, swales and berms remain poorly understood and rarely practiced. The absence of correctly constructed swales during field visits supports the interpretation that low adoption reflects not only limited exposure but also insufficient technical knowledge. Key barriers identified across data sources included lack of training, absence of demonstration plots, and limited extension guidance. Farmers expressed interest in practical training and field-based demonstrations, indicating that improved technical support could enhance informed adoption of underutilized RWH/SMC technologies.

Plate 1: Trench structure observed in a maize field in Dareda Kati village, Babati District. Although superficially resembling a swale, the structure does not meet minimum design criteria for swales and berms (fanya chini), as it lacks contour alignment, a level base, and a clearly formed downhill berm. The trench appears oriented downslope, functioning primarily as a drainage channel rather than an in-situ rainwater harvesting structure. Source: Field photograph taken by authors (2025).

5. Discussion

This study provides context-specific insight into RWH and SMC practices in the Babati highlands of northern Tanzania, a region characterized by relatively high annual rainfall (800-1000 mm) yet existence of runoff and soil erosion challenges. While Babati District is considered an agriculturally high-potential area, the findings reveal limited diversification of RWH/SMC technologies and an almost complete absence of swales and berms despite having a sloping terrain. This paradox, adequate rainfall coupled with sub-optimal in-situ water management represents a key contribution of the study.

The farming population in Dareda Kati and Gajal villages consists largely of experienced maize farmers (mean = 21 years), operating relatively small landholdings (mean = 0.91 ha), consistent with other smallholder systems in SSA (25, 26). While long farming experience suggests familiarity with local agro-ecological conditions, previous studies note that experience may not necessarily translate into innovation adoption, particularly where traditional practices dominate (27). Yield variability was substantial (445–10,675 kg/ha), reflecting heterogeneity in management practices, input access, and environmental conditions, as observed in comparable smallholder contexts (28, 29, 30). Earlier work by (31, 32), similarly highlights low external input use, land degradation, and limited soil water-holding capacity as key productivity constraints.

Importantly, multivariable analysis indicated that neither farming experience nor farm size significantly influenced awareness or adoption of RWH/SMC practices(33). Instead, knowledge exposure emerged as the strongest determinant of both awareness and use, reinforcing evidence that access to information and extension services shapes conservation behavior (34, 35, 36, 37, 38). While differences in practice use may partly correspond with observed yield variability, causal relationships cannot be inferred without controlling for confounding factors. In the Babati highlands, where annual rainfall is relatively high but runoff losses and intra-seasonal dry spells reduce effective water availability, these findings suggest that strengthening technical knowledge and extension engagement may be more critical than farm size or years of experience in promoting adoption of in-situ water management strategies.

Although 67.35% of respondents reported general awareness of RWH/SMC practices, this awareness was uneven across technologies. Fanya juu was the most widely known and adopted practice (37.06%), reflecting its long-standing integration into soil conservation programs across East Africa (39, 40). Its dominance indicates that visible erosion control measures remain the primary adaptation strategy in Babati’s sloping landscape. However, nearly one-quarter of farmers reported no knowledge of any conservation technique, revealing persistent information gaps despite the region’s agricultural prominence.

The most striking finding concerns swales and berms. Despite their technical suitability for sloping rain-fed systems and documented roles in reducing runoff, enhancing infiltration, and improving soil moisture retention (41, 42, 43), only three farmers across both villages reported using them. Logistic regression for swale use did not converge due to quasi-complete separation, statistically confirming their near-total absence. This is particularly notable given the strong runoff dynamics observed in the field and discussed during FGDs. The Babati case therefore illustrates that agro-ecological suitability alone does not guarantee adoption.

From a diffusion of innovation perspective (44, 45), swales and berms appear to lack perceived relative advantage over established practices such as fanya juu, which provide immediate and visible erosion control benefits with comparatively lower complexity. Their perceived complexity, labor requirements, and limited trialability likely constrain uptake. Field observations further revealed confusion between swales and conventional drainage trenches, indicating insufficient technical clarity and absence of demonstration plots. Thus, the constraint is not environmental incompatibility, but informational and institutional limitation. Village-level differences further underscore contextual effects. Farmers in Gajal were significantly more likely to adopt RWH/SMC practices than those in Dareda Kati, suggesting localized variation in extension engagement or peer learning networks. Such micro-contextual variation highlights the importance of village-specific institutional dynamics rather than purely biophysical determinants.

Perceived effectiveness closely mirrored adoption patterns when evaluated among users of each respective technology. Fanya juu was consistently rated as effective or very effective by the majority of its users in both villages, reinforcing its entrenched role in local soil and water management practice (44, 46). Supplementary irrigation and mulching were also positively rated among users, particularly in Gajal, suggesting that repeated exposure and practical experience shape favorable evaluations. In contrast, practices with very low adoption especially swales and berms had extremely small numbers of users, limiting meaningful interpretation of effectiveness ratings. Where rated positively, this likely reflects isolated individual experiences rather than widespread validated performance. The absence of correctly constructed swales in field observations further suggests that limited technical understanding constrains experiential learning. Overall, these findings indicate that perception formation in Babati is strongly experience-driven, underscoring the importance of structured demonstration plots, technical training, and farmer-to-farmer learning to enable informed evaluation of underutilized technologies. Therefore, this study contributes to the literature by showing that in a relatively high-rainfall highland system, low RWH/SMC diversification and minimal adoption of technically suitable innovations can persist due to knowledge gaps and institutional limitations rather than agro-ecological constraints. The near absence of swales and berms in a landscape characterized by runoff-prone slopes represents a missed opportunity for improving in-situ RWH and retention and enhancing resilience under rainfall variability. Targeted, village-specific extension strategies, practical demonstrations, and structured knowledge dissemination are therefore likely to be more impactful than interventions focused solely on structural farm characteristics.

6. Practical Implications for Swales and Berms Promotion

Given the central role of knowledge gaps identified in this study, a structured extension approach is recommended to support correct implementation of swales and berms. District agricultural extension services, in collaboration with research institutions and local NGOs, should establish well-designed demonstration plots on representative sloping fields to provide practical reference sites. Farmers would benefit from hands-on training covering contour identification, leveling techniques, berm construction, and appropriate spacing. Farmer-to-farmer learning mechanisms, such as field days and community exchange visits, could further enhance knowledge dissemination. In addition, periodic follow-up visits during and after rainy seasons are necessary to assess structural integrity, provide technical feedback, and document outcomes such as soil moisture retention, erosion reduction, and yield performance. Intervention success should be evaluated based on correct construction rates, adoption levels, and agronomic performance over multiple seasons.

7. Conclusion

This study reveals a critical gap in rainwater management within the maize-based, rain-fed systems of the Babati highlands. Although general awareness of selected RWH and SMC practices exists, particularly for fanya juu, the diversification of technologies remains limited. Most notably, swales and berms, despite being technically suitable for sloping terrain with high runoff, are almost entirely absent from current farming practice. This indicates that agro-ecological suitability alone is insufficient to drive adoption; knowledge exposure, institutional support, and practical demonstration are central determinants.

To address this gap, district-level agricultural extension services in Babati, in collaboration with local government authorities, research institutions, and relevant NGOs, should establish pilot demonstration plots in representative sloping maize fields. These demonstrations should focus specifically on swale and berm design, contour layout, berm stabilization, outlet construction, and seasonal maintenance. Training should combine classroom instruction with hands-on field-based learning using simple tools such as A-frame levels to ensure farmers acquire practical implementation skills. Participatory approaches such as farmer field schools and peer learning networks may enhance knowledge diffusion and reduce perceived complexity.

Interventions should be evaluated using measurable indicators, including: (i) changes in farmer awareness and adoption rates, (ii) maize yield performance compared with control plots, (iii) soil moisture retention during intra-seasonal dry spells, and (iv) observable reductions in runoff and soil erosion. Monitoring these indicators over multiple seasons would provide robust evidence on the agronomic and economic viability of swales and berms under Babati's bimodal rainfall system, particularly during the high-intensity masika rains (March-April), when harvested water could support maize growth into the drier months (May-July).

While this study did not include direct soil moisture measurements or controlled yield comparisons, it establishes a strong foundation for future experimental trials. Subsequent research should incorporate side-by-side control plots, quantitative soil moisture monitoring, and cost-benefit analysis to rigorously assess the long-term performance of swales and berms. Overall, the findings position this study not only as an assessment of current adoption patterns but also as a practical guideline for strengthening in-situ rainwater management in highland farming systems facing rainfall variability and runoff challenges.

8. Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sampling approach was not fully probability-based, as participants were selected within two villages rather than through district-wide random sampling; therefore, results may not be generalizable to all maize farmers in Babati District or beyond. Second, key variables such as technology use and maize yields were self-reported, which may introduce recall bias or reporting inaccuracies. Third, the study did not include direct biophysical measurements such as soil moisture monitoring, runoff quantification, or hydrological assessments, limiting the ability to empirically validate the agronomic performance of specific RWHTs. Finally, the cross-sectional design captures adoption patterns at a single point in time and does not allow for analysis of longitudinal adoption trends or seasonal dynamics. Future research incorporating randomized sampling, objective yield and soil moisture measurements, and multi-season monitoring would strengthen causal inference and provide more robust evidence on the long-term impacts of swales, berms, and other soil moisture conservation practices.

9. Declarations

9.1 Ethical Approval

This study was conducted in compliance with national and institutional research ethics standards. Ethical approval was obtained from KNCHREC, which is a zonal ethics body comprising the Kibong'oto Infectious Diseases Hospital (KIDH), The Nelson Mandela African Institution of Science and Technology (NM-AIST), and the Centre for Educational Development in Health, Arusha (CEDHA). The Proposed Research, (Research Proposal No: KNCHREC/0002/02/2025) was issued on 8th March 2025. In addition, field research activities were approved by the Babati District Council, which issued an official introduction and authorization letter dated 3 December 2024, permitting the researcher to conduct fieldwork and experimental activities in Ayalagaya Ward. The study adhered to ethical guidelines ensuring respect for participants, communities, and the environment. Informed consent was obtained from all participants prior to data collection. Participation was voluntary, and respondents were assured of confidentiality and anonymity.

9.2 Consent to Participate

Informed consent was obtained from all participants prior to data collection. Participants were informed about the purpose of the study, and their participation was entirely voluntary. They were assured of confidentiality and their right to withdraw from the study at any time without any consequences.

9.3 Consent to Publish

Participants were informed that the data collected would be used for academic and publication purposes. All data have been anonymized to ensure that no individual respondent can be identified.

9.4 Data Availability Statement:

The dataset generated and analyzed during the current study is available in the Zenodo repository at: https://doi.org/10.5281/zenodo.19229456. The dataset includes the guide for questionnaire, FGDs, documentary review and observation. Additional data supporting the findings of this study are available from the corresponding author upon reasonable request.

9.5 Field experiment approval:

Field experimental activities were officially authorized by the Babati District Council, as per the letter issued on 3 December 2024, permitting research activities in Ayalagaya Ward in privately owned fields. The approval covered field observations and on-site assessments of rainwater harvesting structures, as well as engagement with local farmers for data collection and technology demonstration.

Funding: This research was sponsored by Inter-University Council for East Africa (IUCEA), with funding from the World Bank through the Eastern and Southern African Higher Education Centers of Excellence Additional Financing (ACE AF II) Project.

Acknowledgment: We would like to acknowledge the District Executive Director for Babati District Council for permitting us to conduct this study in Babati district. We also acknowledge all the extension staffs, leaders and farmers who participated in the study.

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Potentials of climate smart agriculture in sustaining farming systems through farmer's awareness and rainwater harvesting technologies in northern Tanzania

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Abstract: This study assessed farmers' awareness (knowledge), use (actual implementation), and perceived effectiveness of rainwater harvesting (RWH) and soil moisture conservation (SMC) techniques for maize production in the sloping highlands of Babati District, Tanzania. A mixed-methods cross-sectional design was employed, combining household surveys (n = 147), focus group discussions (FGDs), and field observations in Dareda Kati and Gajal villages in the Babati District to generate both quantitative and qualitative data. Results indicate a clear gap between awareness and use of RWH and SMC techniques. While 67.35% of respondents were aware of general stormwater management practices, awareness and use of swales and berms (fanya chini) for RWH was extremely low. Only 2.9% of the users reported using swales and berms. In contrast, contour bunds (fanya juu) had a highest usage rate (60.0%), reflecting its long-standing promotion through extension programs. Statistical analysis showed no significant differences in awareness levels between the surveyed villages, suggesting that location alone does not explain variations in technology uptake. Farmers' perceptions further revealed limited understanding of the construction and management of less familiar RWH techniques, even among the few adopters. These findings demonstrate that awareness does not necessarily translate into use and that knowledge depth and practical skills are critical for adoption of RWH and SMC on sloping

landscapes. For policy and extension, the results highlight the need for targeted, hands-on training, participatory demonstrations, and strengthened extension support to improve both informed use and correct implementation of low-cost RWH and SMC techniques for resilient maize production under climate variability.

Key words: *Fanya juu, rain water harvesting, soil moisture conservation, farmers' awareness*

1. Introduction

Climate change continues to threaten agricultural productivity in sub-Saharan Africa (SSA), where increased rainfall variability, recurrent droughts, floods, and rising temperatures reduce crop yields and exacerbate food insecurity (1, 2). Maize, the region's staple crop, is cultivated on approximately 27 million hectares; yet average yields remain around 1 t ha^{-1}, far below attainable yields of up to 5 t ha^{-1} under improved management (1). The heavy reliance on rain-fed systems makes smallholder farmers particularly vulnerable to rainfall variability and intra-seasonal dry spells. In northern Tanzania's Babati highlands, annual rainfall ranges between 800 and 1000 mm, generally adequate for maize production (3). However, steep slopes, land degradation, and intense rainfall events contribute to substantial surface runoff, limiting effective rainwater use. Previous studies in Babati and similar highland systems have documented soil erosion, runoff challenges, and the importance of soil and water conservation practices. More broadly, only 15-30% of seasonal rainfall may contribute to crop biomass production due to runoff and evaporation losses (4), underscoring the importance of in-situ rainwater management even in relatively high-rainfall environments. Despite Babati's favorable rainfall totals, efficient rainwater utilization remains constrained by landscape characteristics and management practices.

Rainwater harvesting (RWH) and soil moisture conservation (SMC) practices, including contour bunds (fanya juu), conservation tillage, mulching, and check dams, have demonstrated measurable benefits in reducing runoff and improving soil moisture (4, 5, 6, 7). In Babati, earlier research has primarily emphasized conventional soil conservation measures and general land management practices (8). However, limited attention has been given to the awareness, adoption dynamics, and perceived effectiveness of a broader suite of RWH technologies, particularly swales and berms (fanya chini). Swales and berms are designed to slow runoff and enhance infiltration along contour lines (9), yet their agricultural performance and diffusion within smallholder maize systems in SSA remain underexplored. While engineering studies report that swales can reduce runoff by up to 88% (10, 11), much of this evidence derives from urban stormwater contexts, with minimal empirical assessment in rain-fed smallholder farming systems. Thus, although soil and water conservation challenges in Babati have been documented, there remains a gap in understanding (i) the extent of farmer awareness and use of different in-situ RWH/SMC options, (ii) the determinants of adoption in a high-rainfall yet runoff-prone highland setting, and (iii) why technically suitable interventions such as swales and berms remain largely absent. Addressing these gaps is essential for moving beyond descriptive accounts of erosion challenges toward actionable strategies for improving rainfall utilization.

Previous research on agricultural technology adoption has increasingly employed mixed-methods approaches, combining quantitative surveys with qualitative tools such as focus group discussions and key informant interviews (11, 12). Such designs enable the integration of statistical analysis of adoption patterns with contextual understanding of social and institutional drivers. Building on this body of work, the present study contributes novel empirical evidence from the Babati highlands by systematically assessing farmers' awareness, use, and determinants of RWH/SMC practices, with a specific focus on swales and berms as a potentially suitable yet underutilized technology for sloping maize fields. Unlike prior studies that primarily described conservation challenges or specific practices in isolation, this study integrates quantitative adoption analysis with qualitative insights to identify knowledge gaps and village-level contextual differences influencing technology uptake.

The specific objectives are to: a. Quantify farmers’ awareness and use of different in-situ RWH and SMC techniques.

b. Compare awareness, use, and perceived effectiveness of these techniques between villages. c. Examine determinants of adoption using multivariable analysis.

d. Identify barriers and knowledge gaps regarding swales and berms on sloping maize lands. By clarifying adoption dynamics in a high-rainfall yet runoff-constrained environment, this study provides evidence-based guidance for targeted extension strategies aimed at improving in-situ rainwater management and strengthening maize system resilience under climate variability.

2. Conceptual Framework

This study is guided by a conceptual framework that links climatic, biophysical, and socio-institutional factors to the adoption of RWH and SMC technologies in smallholder maize systems (13). Rainfall variability, slope, and runoff dynamics influence soil moisture availability in sloping fields (14, 15, 16), while farmer awareness, extension support, perceptions, and resource capacity shape the adoption of technologies such as fanya juu (17), fanya chini etc., the adoption and effectiveness of these practices are expected to enhance soil moisture retention, which ultimately affects maize productivity.

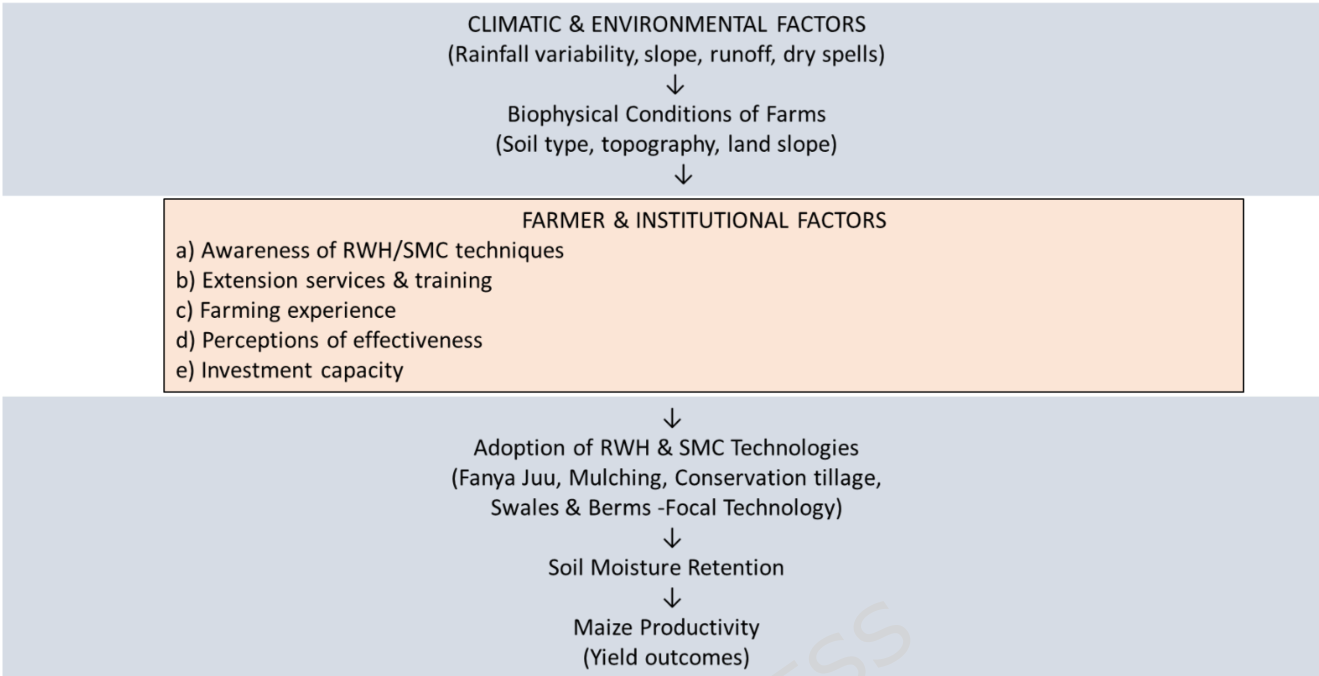

Figure 1: Conceptual framework illustrating the relationships between climatic conditions, farmer awareness, adoption of rainwater harvesting and soil moisture conservation technologies (including swales and berms), and maize productivity in sloping highland farming systems. Source: Authors' field survey data (2025).

3. Materials and Methods

3.1 Description of the Study Site

The study was conducted in Dareda Kati and Gajal villages in Ayalagaya Ward, Babati District Council, Manyara Region, northern Tanzania. Babati District lies between latitudes 3°-5° S and longitudes 35°-37° E within the Great Rift Valley and is characterized by undulating highlands, rolling hills, and mountainous terrain with elevations ranging from 950 to 2,450 m above sea level (18). The sampled maize fields are predominantly located on sloping landscapes, where moderate to steep gradients enhance surface runoff and soil erosion, particularly during intense rainfall events. Such topographic conditions directly influence soil moisture retention and the effectiveness of in-situ rainwater harvesting technologies (RWHTs).

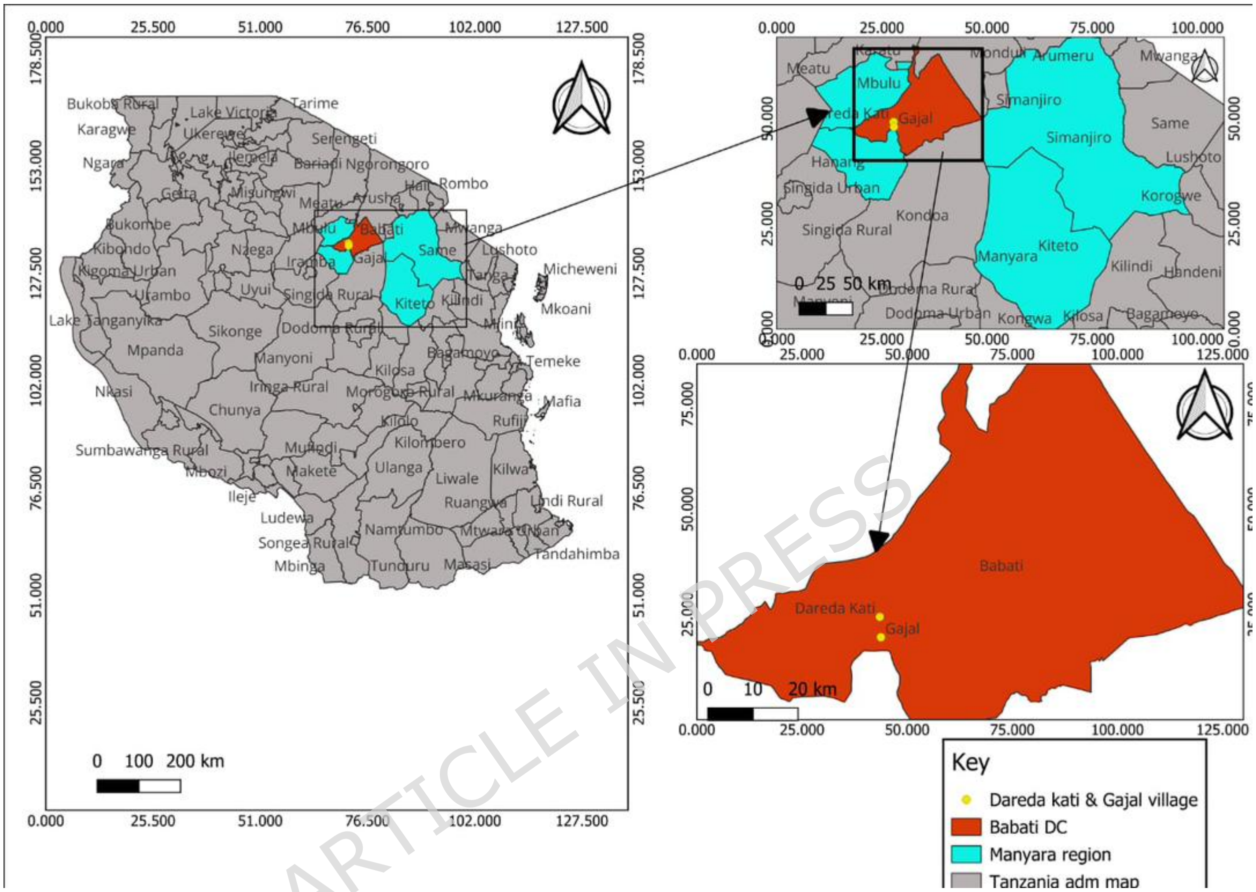

Figure 2: Location of Dareda Kati and Gajal villages in Ayalagaya Ward, Babati District, Manyara Region, northern Tanzania. The map shows the administrative boundaries and the position of the study villages within the district. Source: Authors' compilation based on administrative boundary data and GIS analysis (2025).

Rainfall in the study area follows a bimodal pattern, with short rains occurring from October to December and long rains from February to May. The highland zones receive approximately 800-1000 mm of annual rainfall, with mean temperatures ranging from 10°C to 25°C (3, 19). However, rainfall is not evenly distributed across the growing season. A pronounced dry period occurs from June to September, while peak rainfall is concentrated in March-April and November-December (Figure 2).

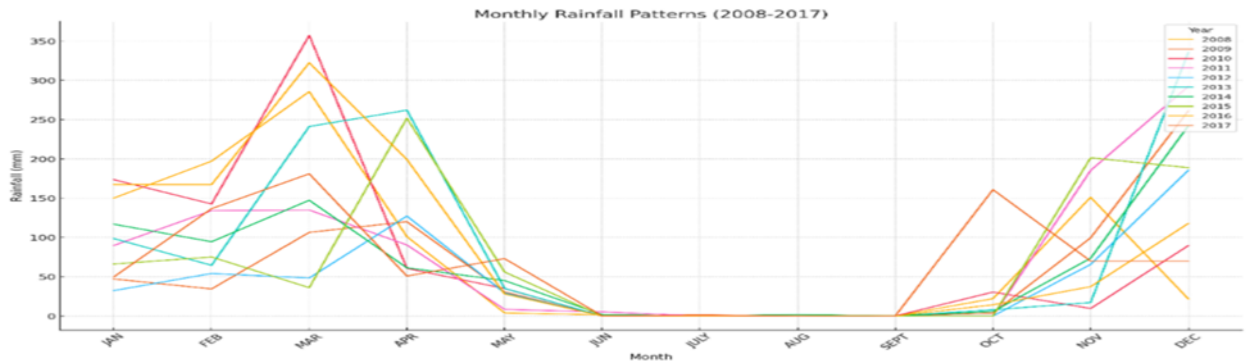

Figure 3: Monthly rainfall distribution in Babati District from 2008 to 2017, illustrating bimodal rainfall peaks and intra-seasonal variability. Source: Babati Meteorological Station (2018).

Analysis of historical rainfall data from Babati Meteorological Station (2008-2018) reveals considerable inter-annual variability, with fluctuations around the long-term average of 800-1000 mm. Monthly records (2008-2017) further indicate irregular rainfall distribution characterized by episodic high-intensity storms followed by intra-seasonal dry spells. Under sloping field conditions, such rainfall patterns increase runoff generation and reduce effective infiltration, leading to sub-optimal soil moisture availability for maize production despite adequate total annual rainfall. These hydro-climatic dynamics underscore the relevance of in-situ rainwater harvesting and soil moisture conservation measures, particularly contour-based practices such as contour bunds (fanya juu) and swales and berms (fanya chini), which are designed to slow runoff and enhance water infiltration.

Soils in the study area are predominantly red sandy loams, grey sandy loams, and red clay loams, which are moderately fertile and suitable for cereal-legume systems (19). Agriculture is the primary livelihood activity, with smallholder farmers mainly practicing rain-fed maize cultivation intercropped with beans, pigeon peas, and sunflower (3). Given the combination of sloping terrain, variable rainfall, and reliance on rain-fed maize production, the study area provides a suitable context for assessing farmers' awareness and use of rainwater harvesting and soil moisture conservation technologies.

3.2 Definition of Terms

In this study, RWH refers to in-situ practices designed to capture, slow, and enhance infiltration of rainfall or surface runoff within the field. SMC, also referred to as soil moisture retention (SMR), refers to practices that reduce evaporation losses and maintain soil water within the root zone for improved crop uptake. While conceptually distinct, several practices serve both functions simultaneously by reducing runoff and improving infiltration while also enhancing soil water retention. For analytical clarity, practices were categorized according to their primary functional objective, although some techniques are recognized as contributing to both RWH and SMC processes.

Table 1. Classification of rainwater harvesting and soil moisture conservation practices. Source: Authors' field survey data (2025).

Practice	**Primary Classification**	**Functional Role**
Contour Bunds (Fanya juu)	RWH & SMC	Reduces runoff, controls erosion, enhances infiltration
Swales and berms (Fanya chini)	RWH & SMC	Captures runoff along contour, increases infiltration and soil moisture
Kinga Maji (Water diversion structures)	RWH	Redirects surface runoff to reduce erosion
Supplementary irrigation	RWH	Applies harvested water to crops during dry periods

Practice	Primary Classification	Functional Role
Mulching	SMC	Reduces evaporation, improves soil moisture retention
Minimum tillage	SMC	Improves soil structure and water retention
Cover cropping	SMC	Enhances soil cover, reduces evaporation and erosion
Use of manure/Organic inputs	SMC	Improves soil organic matter and water-holding capacity

3.3 Study Design

A mixed-methods approach (surveys, focus group discussions, and field observations) was used to capture both quantitative adoption patterns and qualitative insights on barriers, perceptions, and implementation practices. A semi-structured questionnaire comprising both closed and open-ended questions was developed and pre-tested to refine question wording and estimate the time required for administration. The questionnaire has been deposited in the Zenodo repository and is available at: https://doi.org/10.5281/zenodo.19229456. The questionnaire variables were organized into four major categories to enhance analytical clarity: (i) socio-demographic characteristics, (ii) farm characteristics, (iii) awareness and use of rainwater harvesting (RWH) and soil moisture conservation (SMC) practices, and (iv) farmer perceptions and constraints. In the same upload, there is a section (Section E), containing the guide for Focus Group Discussion (FGD) with Key Informants and also a guide for field observations.

3.4 Sample Size Determination

To determine the required survey sample size, a priori power analysis was conducted using G*Power 3.1. The calculation was based on a two-sample comparison between villages (Dareda Kati vs. Gajal), reflecting the study's objective of examining inter-village differences in awareness and use of RWH and SMC practices (20). A small effect size (Cohen's d = 0.233) was selected to reflect the expectation of modest differences between villages in adoption-related outcomes, consistent with prior smallholder technology adoption studies in similar contexts. The analysis assumed a significance level (α) of 0.05, statistical power of 0.80, and equal allocation (1:1) between villages. Under these assumptions, a minimum total sample of 147 respondents was required. Although the primary power calculation was based on a two-sample comparison framework, the final sample size was also sufficient for subsequent logistic regression analyses examining determinants of awareness and adoption, ensuring adequate statistical reliability for both comparative and multivariable analyses.

3.5 Data Collection

The study was conducted in two purposively selected villages; Dareda Kati and Gajal in Babati District, northern Tanzania (21). The villages were selected based on their prominence in maize production, sloping topography, and reported runoff challenges, making them suitable contexts for assessing RWH and SMC practices. According to village administrative records and consultation with local agricultural officers, both villages are dominated by smallholder maize-farming households. All maize farmers aged 18 years and above were considered eligible for participation.

Data collection was conducted between March and April 2025 through face-to-face interviews with 147 purposively selected smallholder farmers from Dareda Kati and Gajal villages. Each farmer was interviewed individually to ensure independence of responses, and each interview lasted approximately 10 minutes. The questionnaire was originally developed in English and administered using an interviewer-assisted approach. During data collection, the research team, consisting of the principal researcher and three trained enumerators, operated in pairs. In each pair, one member administered the questionnaire by reading and translating the questions orally into Swahili to ensure clarity and comprehension, while the other recorded the responses provided by the farmer. All enumerators received prior training to ensure consistency in translation and data recording procedures. Upon completion of fieldwork, the collected data were reviewed, cleaned, and subsequently analyzed using appropriate statistical and qualitative analysis techniques.

Participants recruitment was facilitated through collaboration with village leaders and ward-level agricultural extension officers (22). A community meeting was scheduled on a non-market weekday afternoon at the agricultural office compound in each village to maximize attendance and minimize interference with farming activities. All maize farmers were invited through village announcements, ensuring open participation rather than selective nomination (23, 24). During the meeting, the research team introduced the study objectives and procedures in both English and Kiswahili, and informed consent was obtained from all willing participants.

Within each village, simple random sampling was then applied among meeting attendees using folded papers labeled “Today,” “Tomorrow,” and blank to allocate survey participation. In Dareda Kati, 75 farmers were selected for the interviewer-administered survey and 5 participants (community elders and extension officers) were selected for one focus group discussion (FGD). In Gajal, 72 farmers were selected for the survey and 5 (community elders and ward extension officers) for 1 FGD using the same procedure. FGDs captured expert and community-level insights. In general, 2 Focus Group Discussions (FGDs) were held with 10 key informants (community leaders, and agricultural extension officers) purposively selected from the two villages to gather in-depth insights on group-level practices, historical changes, and perceived barriers to technologies adoption. A group size of five participants per village was considered adequate for FGDs, as the discussions aimed to capture informed expert perspectives rather than statistical representation, and sessions were continued until no new substantial insights emerged, indicating adequacy of information (saturation).

Because village selection was purposive and participation was limited to farmers who attended the community meeting, the sample should be interpreted as context-specific rather than statistically representative of all maize farmers in Babati District. While random allocation was used among attendees, farmers who did not attend the meeting may differ systematically from participants. Therefore, findings provide analytical insights into adoption patterns within the selected villages but should not be generalized to the wider district without caution. In addition, selected participants' farms were visited for direct field observations to verify the presence of practices such as swales and berms, and other land management features.

Direct field observations (on the evidence of use of RWH and SMC practices, topographical characteristics of the area and general land management practices) complemented other data sources, enhancing the overall quality of the dataset. Descriptive variables such as village, farming experience, and farm size were used to characterize respondents, while awareness, perceptions, and investment in RWH and SMC were treated as independent variables influencing technology adoption. The primary dependent variables included the use of RWH and SMC techniques, particularly swales and berms, and perceived effectiveness in improving soil moisture and maize productivity. Qualitative data from FGD and field observations were used to contextualize adoption patterns, identify barriers, and validate reported practices.

Table 2. Structured overview of questionnaire variables grouped into socio-demographic characteristics, farm characteristics, rainwater harvesting and soil moisture conservation practices, and farmer perceptions, indicating the

role of each variable as dependent, independent, or descriptive in the analysis. Source: Authors' field survey data (2025).

Category	Data Type	Method	Key Variables Collected	Variable Role in Analysis
Socio-demographic characteristics	Quantitative	Survey (interviewer-administered)	Role in community, village, years of maize farming experience	Descriptive
Farm characteristics	Quantitative	Survey & Observation	Farm size (acres), maize yield (bags), land slope (observed), land management practices	Independent / Descriptive
RWH & SMC practices	Quantitative & Qualitative	Survey, Observation	Awareness of RWH/SMC techniques, use of fanya juu, swales and berms (fanya chini), soil moisture monitoring frequency, investment in RWH/SMC (TZS)	Independent (key predictors)

Category	Data Type	Method	Key Variables Collected	Variable Role in Analysis
Perceptions and effectiveness	Quantitative & Qualitative	Survey & FGDs	Perceived effectiveness of RWH/SMC techniques, importance of soil moisture, most effective yield improvement methods	Independent / Explanatory
Barriers and adoption context	Qualitative	Focus Group Discussions (FGDs)	Barriers to adoption, historical adoption trends, extension support, knowledge gaps on swales and berms	Explanatory (qualitative)
Biophysical observations	Qualitative	Field Observation	Presence of fanya juu structures, swales and berms, topographical characteristics, runoff indicators	Supporting / Validation

Table 3. Field observation checklist for rainwater harvesting and soil moisture conservation technologies. Source: Authors’ field survey data (2025).

Technology	Observation Criteria	Minimum Criteria for Classification as Properly Constructed
Contour bunds (Fanya juu)	Presence of trench and uphill bund; alignment along contour; bund continuity; visible sediment deposition	Continuous bund aligned with contour and evidence of runoff control
Swales and berms (Fanya chini)	Trench aligned along contour; level trench base; excavated soil formed into downhill berm; absence of downslope drainage orientation	Contour alignment + level base + clearly formed downhill berm
Water diversion structures (Kinga maji)	Diversion channel present; direction of water flow controlled; erosion protection structures	Structured diversion aligned to safely redirect runoff
Minimum tillage	Reduced soil disturbance; visible crop residue retention	Minimal soil inversion with retained surface cover
Mulching	Visible organic cover on soil surface	≥ partial surface cover with plant residue or organic matter
Cover cropping	Presence of live cover crop or intercropped legumes/grasses	Intentional vegetative ground cover maintained

3.6 Data Analysis

Prior to analysis, variables were categorized as dependent, independent, and descriptive to ensure consistency between the study objectives, conceptual framework, and statistical interpretation. Quantitative data were entered, cleaned, and analyzed using R software version 4.4.1. Descriptive statistics (means, medians, standard deviations, frequencies) and logistic regression models were used to summarize farm characteristics, awareness levels, and technology use. Inferential analysis included: Pearson's chi-squared tests (to assess relationships between categorical variables, e.g., village vs. awareness), fisher's exact test (when expected cell counts <5), and independent-sample t-tests (to compare continuous variables like maize yield). Qualitative data from FGD were subjected to thematic analysis, where emerging themes related to perceptions, constraints, and recommendations were identified, coded, and integrated into the discussion.

3.7 Ethical Approval

Ethical approval for this study was obtained from KNCHREC, which is a zonal ethics body comprising the Kibong'oto Infectious Diseases Hospital (KIDH), The Nelson Mandela African Institution of Science and Technology (NM-AIST), and the Centre for Educational Development in Health, Arusha (CEDHA); (Approval No: KNCHREC/0002/02/2025, approved on 8th March 2025). Informed consent was obtained from all participants prior to data collection, and participants were assured of confidentiality and anonymity.

4. Results

4.1 Information on Years of Experience in Maize Farming, Field Size and Yield of the Respondents

A total of 147 maize-growing farmers participated in the survey, including 75 respondents from Dareda Kati and 72 from Gajal. All respondents reported prior experience in maize production. Farming experience ranged from 2 to 52 years, with a mean of 21 years (SD = 12.81). Half of the respondents had 20 years or less of experience, while 25% had 10 years or less and 75% had up to 29.50 years. Farmers in Dareda Kati reported slightly higher average experience (22 years) compared to Gajal (19 years).

Farmers reported maize field size in acres, which were converted to hectares (1 acre = 0.41 ha) for standardization and comparability. After conversion, field sizes ranged from 0.20 ha to 3.20 ha, with an overall mean of 0.91 ha (SD = 0.59). Approximately 25% of fields measured 0.40 ha or less, while 75% were 1.20 ha or smaller, indicating predominantly smallholder production systems. Dareda Kati had a slightly larger mean field size (0.97 ha) than Gajal (0.85 ha), although Gajal exhibited greater variability (SD = 0.63) compared to Dareda Kati (SD = 0.55).

Maize yield was self-reported in bags per acre. To standardize reporting, yields were converted to kilograms per hectare (kg/ha). Farmers reported harvested maize in standard 100 kg bags. Reported production was first converted to kilograms by multiplying the number of bags by 100 kg. Field size, originally reported in acres, was converted to hectares prior to calculation. Yield was computed using the following formula:

$$\text{Yield (kg/ha)} = \frac{\text{Number of bags} \times 100\ \text{kg}}{\text{Field size (acres)} \times 0.41}$$

Based on this conversion, maize grain yield ranged from 445 kg/ha to 10,675 kg/ha, with a mean of 3,429 kg/ha and a median of 3,558 kg/ha. The interquartile range indicates that 25% of fields produced 2,224 kg/ha or less, while 75% produced up to 4,448 kg/ha. Average yield was slightly higher in Gajal (3,469 kg/ha) than in Dareda Kati (3,391 kg/ha), with greater variability observed in Gajal (SD = 1,484 kg/ha) relative to Dareda Kati (SD = 1,384 kg/ha). Farmers reported yields for dried grain under typical local storage conditions; no independent adjustment for moisture content was applied.

To ensure internal consistency, reported harvest quantities (bags) and field sizes (acres) were cross-checked during interviews. All unit conversions (acres to hectares and bags to kilograms) were verified during data entry. Implausible combinations of area and production were reviewed and corrected where necessary. Descriptive screening was conducted to identify extreme outliers prior to analysis. Although yield data were self-reported and may be subject to recall bias, these validation procedures were implemented to minimize measurement and conversion errors.

Table 4: An overview of farmers' years of experience, maize field size and grain yield (N = 147). Source: Authors' field survey data (2025).

Variable	Village	Mean	SD
Years of experience	**All Villages**	20.91	12.81
	Dareda Kati	22.40	13.30
	Gajal	19.40	12.20
Maize field size (ha)	**All Villages**	0.91	0.59
	Dareda Kati	0.97	0.55
	Gajal	0.85	0.63
Maize grain yield (kg/ha)	**All Villages**	3429	1429
	Dareda Kati	3391	1384
	Gajal	3469	1484

4.2 Awareness of in-Situ Rainwater Harvesting and Soil Moisture Conservation Techniques

Overall, 99 out of 147 farmers (67.35%) reported being aware of RWH technologies, while 48 farmers (32.65%) reported no awareness. At the village level, awareness was 64.0% (48/75) in Dareda Kati and 70.83% (51/72) in Gajal, representing a difference of 6.83 percentage points in favor of Gajal. A Pearson's chi-squared test with Yates' continuity correction was conducted to examine whether awareness differed by village. The association was not statistically significant ($\chi^2 = 0.50$, df = 1, $p = 0.48$). The estimated difference in awareness between villages was 6.83 percentage points (95% CI: approximately -8% to 22%), indicating considerable uncertainty around the true magnitude of the difference. While the statistical test does not provide evidence of a significant association between village and awareness, the confidence interval suggests that both small negative and moderate positive differences remain plausible. These findings indicate broadly comparable levels of awareness between the two villages, although modest differences cannot be ruled out.

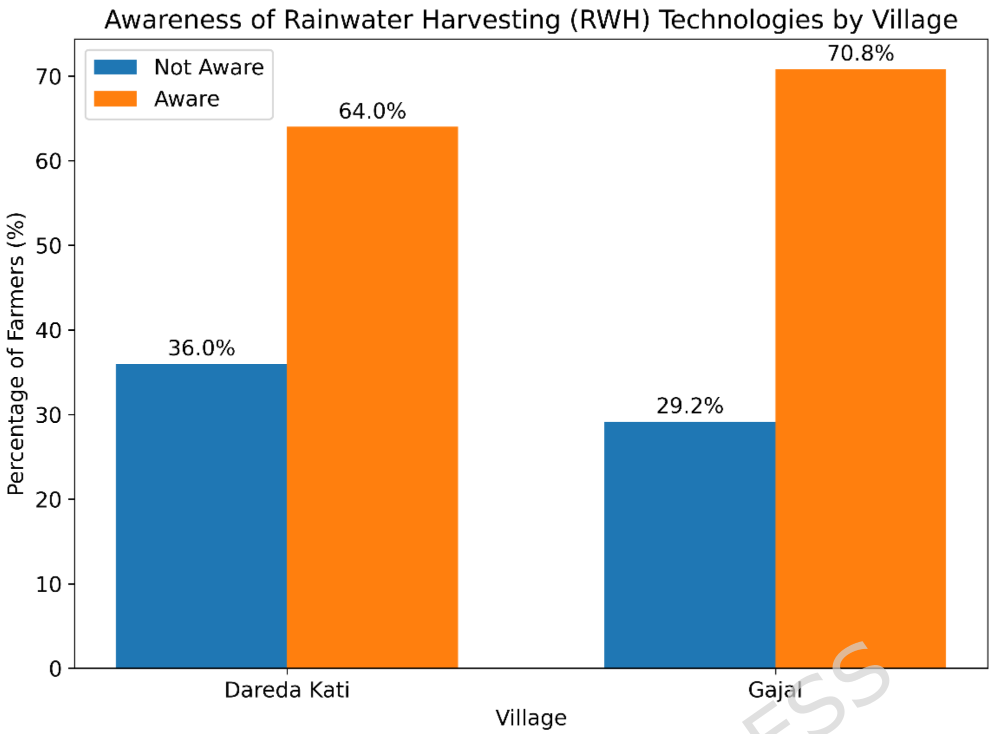

Figure 4. Percentage of farmers aware and not aware of rainwater harvesting technologies in Dareda Kati (n = 75) and Gajal (n = 72), Babati District, northern Tanzania. Awareness levels were broadly comparable between villages, with slightly higher reported awareness in Gajal. Source: Authors' field survey data (2025)

4.3 Rainwater Harvesting and Soil Moisture Conservation Techniques Used by Maize Growing Farmers

Out of the 147 surveyed farmers, 105 (71.4%) reported using at least one RWH/ or SMC practice, while 42 farmers (28.6%) did not use any technique. Among users (N = 105), *fanya juu* was the most widely implemented practice, reported by 63 farmers (60.0%). Supplementary irrigation (26 farmers; 24.8%) and mulching (24 farmers; 22.9%) were also commonly practiced, mainly to address delayed rainfall onset and intra-seasonal dry spells. Usage of other techniques was limited: *kinga maji* (5 farmers; 4.8%), minimum tillage (4 farmers; 3.8%), swales and berms (3 farmers; 2.9%), and cover cropping (3 farmers; 2.9%). Because multiple responses were allowed, percentages exceed 100%.

At the village level, clear differences in implementation were observed. In Dareda Kati (n = 75), *fanya juu* was the dominant practice (38 farmers), while fewer farmers reported using supplementary irrigation (8), mulching (7), *kinga maji* (4), minimum tillage (2), and swales and berms (2). No farmers reported the use of cover cropping in this village. In contrast, Gajal (n = 72) showed relatively more diversified adoption. Although *fanya juu* remained the most common practice (25 farmers), higher numbers were recorded for supplementary irrigation (18 farmers) and mulching (17 farmers) compared to Dareda Kati. Limited uptake was observed for *kinga maji* (1), minimum tillage (2), swales and berms (1), and cover cropping (3). These findings indicate that while *fanya juu* dominate in both villages, Gajal farmers demonstrate relatively greater use of moisture-retention and supplementary water management practices. Figure 5 illustrates the village-wise distribution of RWH and SMC techniques.

Table 5. Frequency and percentage of farmers using at least one rainwater harvesting and soil moisture conservation practice (N = 105). Multiple responses were allowed; percentages therefore do not sum to 100%. Source: Authors’ field survey data (2025).

Technique	**Number of Farmers**	**% of Users (N = 105)**
Contour bunds (fanya juu)	63	60.0
Supplementary irrigation	26	24.8
Mulching	24	22.9
Kinga maji	5	4.8
Minimum tillage	4	3.8

Technique	Number of Farmers	% of Users (N = 105)
Swales and berms (fanya chini)	3	2.9
Cover cropping	3	2.9

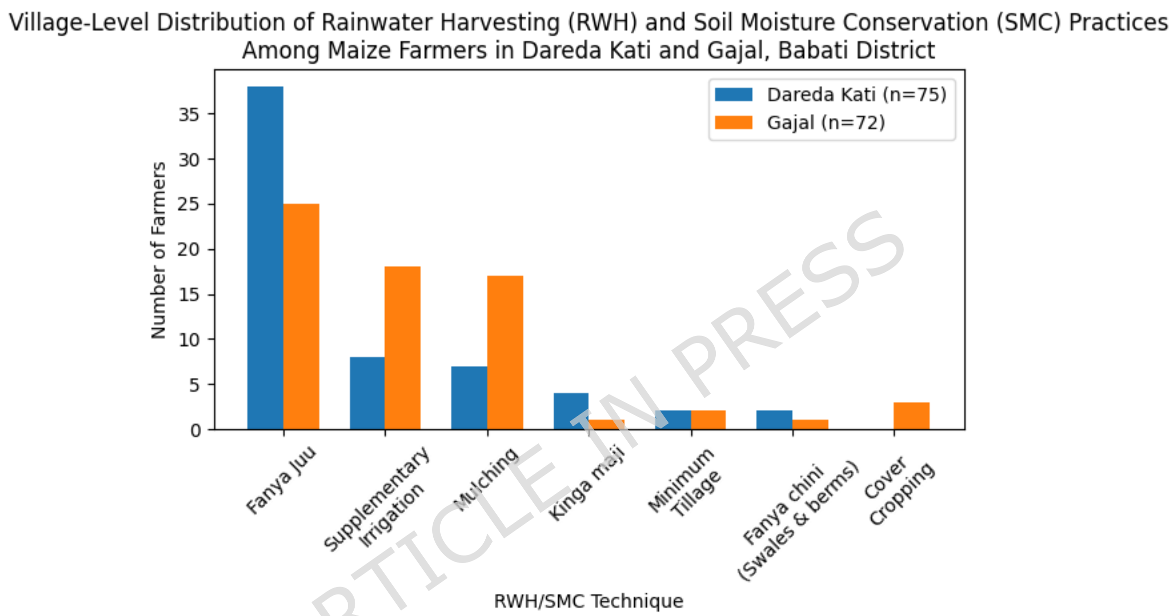

Figure 5. Village-level distribution of rainwater harvesting and soil moisture conservation practices among maize farmers in Dareda Kati (n = 75) and Gajal (n = 72), Babati District, northern Tanzania. Source: Authors' field survey data (2025).

4.4 Comparative Perceptions of Techniques' Effectiveness

Perceived effectiveness was evaluated only among farmers who reported using each respective technology to ensure comparable denominators and avoid conflating awareness with performance assessment. Among fanya juu users, perceptions were overwhelmingly positive in both villages. In Dareda

Kati (n = 38), half of the users (50.0%) rated the practice as very effective, 42.1% as effective, and 7.9% as neutral. In Gajal (n = 25), perceptions were even more favorable, with 76.0% rating it very effective and 24.0% effective. No respondents rated the practice as ineffective in either village, reinforcing its strong perceived performance in runoff and erosion control. For supplementary irrigation, positive perceptions were also evident, though slightly stronger in Gajal. In Dareda Kati (n = 8), 75.0% rated it effective, while 12.5% each rated it neutral and very effective. In Gajal (n = 18), 61.1% rated it effective and 38.9% very effective, with no neutral responses. Mulching was similarly well regarded. In Dareda Kati (n = 7), 71.4% rated it effective, 14.3% very effective, and 14.3% neutral. In Gajal (n = 17), evaluations were evenly split between effective (47.1%) and very effective (47.1%), with only 5.9% neutral. Low-frequency practices (n ≤ 4 per village), including kinga maji, minimum tillage, cover cropping, and swales and berms, were not interpreted due to limited sample sizes. Overall, perceived effectiveness closely aligns with usage patterns. Widely used practices particularly fanya juu and supplementary irrigation received consistently strong evaluations, suggesting that farmer uptake is reinforced by positive experiential outcomes.

Table 6. Perceived effectiveness of rainwater harvesting and soil moisture conservation practices among users. Source: Authors' field survey data (2025).

Village	Technique	Users (n)	Effective (%)	Neutral (%)	Very Effective (%)
Dareda Kati	Fanya juu	38	42.1	7.9	50.0
Gajal	Fanya juu	25	24.0	0.0	76.0
Dareda Kati	Supplementary irrigation	8	75.0	12.5	12.5

Village	Technique	Users (n)	Effective (%)	Neutral (%)	Very Effective (%)
Gajal	Supplementary irrigation	18	61.1	0.0	38.9
Dareda Kati	Mulching	7	71.4	14.3	14.3
Gajal	Mulching	17	47.1	5.9	47.1

4.5 Logistic Regression Models.

A multivariable logistic regression model was fitted to examine determinants of awareness of RWHTs. The model included maize farming experience, farm size, village, and knowledge of soil and water conservation techniques as predictors (n = 143). Results indicated that knowledge of conservation techniques was significantly associated with awareness of RWHT ($\beta = 1.01$, $p = 0.01$). Farmers who reported knowledge of at least one technique were approximately 2.75 times more likely to be aware of RWHT compared to those who did not report such knowledge. In contrast, farming experience ($p = 0.47$), farm size ($p = 0.49$), and village ($p = 0.68$) were not statistically significant predictors. The overall model demonstrated modest explanatory power (Pseudo $R^2 = 0.05$) but provides exploratory evidence that knowledge exposure plays a central role in awareness of rainwater harvesting practices.

Also, a logistic regression model was fitted to examine determinants of swales and berms use. However, the model did not converge due to quasi-complete separation, indicating that very few farmers reported using swales and berms. This suggests extremely low adoption levels within the study area, limiting the ability to statistically estimate determinants of use. The near absence of adoption reinforces qualitative findings that swales and berms remain underutilized despite their suitability for sloping terrain.

Lastly, a multivariable logistic regression model was fitted to examine determinants of use of any RWH or SMC technique (n = 147). The model was statistically significant (LLR $p < 0.001$) and demonstrated strong explanatory power (Pseudo $R^2 = 0.569$). Knowledge of conservation techniques was a highly significant predictor of adoption ($\beta = 4.63$, $p < 0.001$), with farmers who reported knowledge being approximately 102 times more likely to use at least one RWH/SMC practice compared to those without such knowledge. Village location was also significant ($\beta = 1.53$, $p = 0.024$), indicating that farmers in Gajal were approximately 4.6 times more likely to adopt RWH/SMC techniques than those in Dareda Kati. In contrast, farming experience and farm size were not statistically significant predictors. These findings highlight the central role of knowledge exposure and local contextual factors in shaping adoption of rainwater harvesting practices.

Table 7. Multivariable Logistic Regression Models for Awareness and Adoption of Rainwater Harvesting and Soil Moisture Conservation Techniques

Model 1: Determinants of Awareness of RWHTs (n = 143)

Variable	Coefficient (β)	Odds Ratio (OR)	p-value	Significance
Farming Experience	—	—	0.47	Not significant
Farm Size	—	—	0.49	Not significant
Village	—	—	0.68	Not significant
Knowledge of Conservation Techniques	1.01	2.75	0.01	*
Constant	—	—	—	—

Model statistics:

Pseudo $R^2 = 0.05$

n = 143

Model 2: Determinants of Swales and Berms Use

The logistic regression model did not converge due to quasi-complete separation, indicating extremely low adoption of swales and berms among respondents. Consequently, regression coefficients could not be reliably estimated.

Model 3: Determinants of Use of Any RWH/SMC Technique (n = 147)

Variable	Coefficient (β)	Odds Ratio (OR)	p-value	Significance
Farming Experience	—	—	>0.05	Not significant
Farm Size	—	—	>0.05	Not significant
Village (Gajal vs Dareda Kati)	1.53	4.60	0.024	*
Knowledge of Conservation Techniques	4.63	102.00	<0.001	***
Constant	—	—	—	—

Model statistics:

Pseudo $R^2 = 0.569$

LLR $p < 0.001$

n = 147

4.6 Results from Focus Group Discussions and Field Observations

Findings from the focus group discussions (FGDs), survey responses, and direct field observations were triangulated to enhance the reliability of results regarding the awareness and usage of RWH/SMC technologies. Across FGDs, soil erosion on sloping lands was consistently identified as a major challenge, contributing to nutrient loss, declining soil quality, and lower yields compared to lowland areas. These concerns were consistent with survey results indicating that fanya juu was the most widely practiced RWH/SMC technique in both villages.

Survey data showed relatively high reported usage of fanya juu, particularly among farmers cultivating steep slopes. This pattern was corroborated through field observations, where fanya juu structures were visibly present in several maize fields. observations were conducted on 46 farms to verify reported practices. Fanya juu structures were observed on 35 farms and generally met minimum criteria, including contour alignment and visible sediment retention. In contrast, although one farm displayed a trench resembling a swale, it did not meet the defined criteria (lacking contour alignment and a formed downhill berm). No properly constructed swales and berms were observed. Very few farms showed evidence of kinga maji, minimum tillage, or cover cropping, consistent with survey findings. These observations corroborate survey and FGD results, strengthening triangulation. The structures were generally identifiable by uphill bunds formed from soil excavated from trenches below them. In most cases, bunds followed the contour lines, and sediment accumulation behind the bunds provided visible evidence of runoff reduction and soil retention. Although minor deviations in alignment and trench dimensions were observed, the functionality of these structures in controlling erosion was evident.

In contrast, reported awareness and usage of swales and berms were extremely low in both survey and FGD findings. To avoid overstating usage, there was a distinction between self-reported use and correct technical identification based on defined structural criteria. FGDs revealed that several participants who claimed familiarity with swales frequently confused them with drainage trenches or irrigation channels, as both involve excavation. This misunderstanding was verified during field visits. Although one structure partially resembled a swale and berm (Plate 1), closer inspection showed that it did not meet minimum design criteria, including contour alignment, a level trench base, and formation of a downhill berm. Most trenching observed in fields was oriented downslope to facilitate water drainage rather than along contour lines to enhance infiltration. Consequently, while a small number of farmers reported awareness or/and use, no correctly constructed swales and berms were verified in the field. These findings indicate that self-reported awareness may overestimate functional knowledge and proper implementation, underscoring the importance of distinguishing between nominal recognition and correct technical understanding.

The convergence of survey responses, FGD discussions, and physical verification strengthens confidence in the conclusion that while fanya juu is widely understood and properly implemented, swales and berms remain poorly understood and rarely practiced. The absence of correctly constructed swales during field visits supports the interpretation that low adoption reflects not only limited exposure but also insufficient technical knowledge. Key barriers identified across data sources included lack of training, absence of demonstration plots, and limited extension guidance. Farmers expressed interest in practical training and field-based demonstrations, indicating that improved technical support could enhance informed adoption of underutilized RWH/SMC technologies.

Plate 1: Trench structure observed in a maize field in Dareda Kati village, Babati District. Although superficially resembling a swale, the structure does not meet minimum design criteria for swales and berms (fanya chini), as it lacks contour alignment, a level base, and a clearly formed downhill berm. The trench appears oriented downslope, functioning primarily as a drainage channel rather than an in-situ rainwater harvesting structure. Source: Field photograph taken by authors (2025).

5. Discussion

This study provides context-specific insight into RWH and SMC practices in the Babati highlands of northern Tanzania, a region characterized by relatively high annual rainfall (800-1000 mm) yet existence of runoff and soil erosion challenges. While Babati District is considered an agriculturally high-potential area, the findings reveal limited diversification of RWH/SMC technologies and an almost complete absence of swales and berms despite having a sloping terrain. This paradox, adequate rainfall coupled with sub-optimal in-situ water management represents a key contribution of the study.

The farming population in Dareda Kati and Gajal villages consists largely of experienced maize farmers (mean = 21 years), operating relatively small landholdings (mean = 0.91 ha), consistent with other smallholder systems in SSA (25, 26). While long farming experience suggests familiarity with local agro-ecological conditions, previous studies note that experience may not necessarily translate into innovation adoption, particularly where traditional practices dominate (27). Yield variability was substantial (445–10,675 kg/ha), reflecting heterogeneity in management practices, input access, and environmental conditions, as observed in comparable smallholder contexts (28, 29, 30). Earlier work by (31, 32), similarly highlights low external input use, land degradation, and limited soil water-holding capacity as key productivity constraints.

Importantly, multivariable analysis indicated that neither farming experience nor farm size significantly influenced awareness or adoption of RWH/SMC practices(33). Instead, knowledge exposure emerged as the strongest determinant of both awareness and use, reinforcing evidence that access to information and extension services shapes conservation behavior (34, 35, 36, 37, 38). While differences in practice use may partly correspond with observed yield variability, causal relationships cannot be inferred without controlling for confounding factors. In the Babati highlands, where annual rainfall is relatively high but runoff losses and intra-seasonal dry spells reduce effective water availability, these findings suggest that strengthening technical knowledge and extension engagement may be more critical than farm size or years of experience in promoting adoption of in-situ water management strategies.

Although 67.35% of respondents reported general awareness of RWH/SMC practices, this awareness was uneven across technologies. Fanya juu was the most widely known and adopted practice (37.06%), reflecting its long-standing integration into soil conservation programs across East Africa (39, 40). Its dominance indicates that visible erosion control measures remain the primary adaptation strategy in Babati's sloping landscape. However, nearly one-quarter of farmers reported no knowledge of any conservation technique, revealing persistent information gaps despite the region's agricultural prominence.

The most striking finding concerns swales and berms. Despite their technical suitability for sloping rain-fed systems and documented roles in reducing runoff, enhancing infiltration, and improving soil moisture retention (41, 42, 43), only three farmers across both villages reported using them. Logistic regression for swale use did not converge due to quasi-complete separation, statistically confirming their near-total absence. This is particularly notable given the strong runoff dynamics observed in the field and discussed during FGDs. The Babati case therefore illustrates that agro-ecological suitability alone does not guarantee adoption.

From a diffusion of innovation perspective (44, 45), swales and berms appear to lack perceived relative advantage over established practices such as fanya juu, which provide immediate and visible erosion control benefits with comparatively lower complexity. Their perceived complexity, labor requirements, and limited trialability likely constrain uptake. Field observations further revealed confusion between swales and conventional drainage trenches, indicating insufficient technical clarity and absence of demonstration plots. Thus, the constraint is not environmental incompatibility, but informational and institutional limitation. Village-level differences further underscore contextual effects. Farmers in Gajal were significantly more likely to adopt RWH/SMC practices than those in Dareda Kati, suggesting localized variation in extension engagement or peer learning networks. Such micro-contextual variation highlights the importance of village-specific institutional dynamics rather than purely biophysical determinants.

Perceived effectiveness closely mirrored adoption patterns when evaluated among users of each respective technology. Fanya juu was consistently rated as effective or very effective by the majority of its users in both villages, reinforcing its entrenched role in local soil and water management practice (44, 46). Supplementary irrigation and mulching were also positively rated among users, particularly in Gajal, suggesting that repeated exposure and practical experience shape favorable evaluations. In contrast, practices with very low adoption especially swales and berms had extremely small numbers of users, limiting meaningful interpretation of effectiveness ratings. Where rated positively, this likely reflects isolated individual experiences rather than widespread validated performance. The absence of correctly constructed swales in field observations further suggests that limited technical understanding constrains experiential learning. Overall, these findings indicate that perception formation in Babati is strongly experience-driven, underscoring the importance of structured demonstration plots, technical training, and farmer-to-farmer learning to enable informed evaluation of underutilized technologies. Therefore, this study contributes to the literature by showing that in a relatively high-rainfall highland system, low RWH/SMC diversification and minimal adoption of technically suitable innovations can persist due to knowledge gaps and institutional limitations rather than agro-ecological constraints. The near absence of swales and berms in a landscape characterized by runoff-prone slopes represents a missed opportunity for improving in-situ RWH and retention and enhancing resilience under rainfall variability. Targeted, village-specific extension strategies, practical demonstrations, and structured knowledge dissemination are therefore likely to be more impactful than interventions focused solely on structural farm characteristics.

6. Practical Implications for Swales and Berms Promotion

Given the central role of knowledge gaps identified in this study, a structured extension approach is recommended to support correct implementation of swales and berms. District agricultural extension services, in collaboration with research institutions and local NGOs, should establish well-designed demonstration plots on representative sloping fields to provide practical reference sites. Farmers would benefit from hands-on training covering contour identification, leveling techniques, berm construction, and appropriate spacing. Farmer-to-farmer learning mechanisms, such as field days and community exchange visits, could further enhance knowledge dissemination. In addition, periodic follow-up visits during and after rainy seasons are necessary to assess structural integrity, provide technical feedback, and document outcomes such as soil moisture retention, erosion reduction, and yield performance. Intervention success should be evaluated based on correct construction rates, adoption levels, and agronomic performance over multiple seasons.

7. Conclusion

This study reveals a critical gap in rainwater management within the maize-based, rain-fed systems of the Babati highlands. Although general awareness of selected RWH and SMC practices exists, particularly for fanya juu, the diversification of technologies remains limited. Most notably, swales and berms, despite being technically suitable for sloping terrain with high runoff, are almost entirely absent from current farming practice. This indicates that agro-ecological suitability alone is insufficient to drive adoption; knowledge exposure, institutional support, and practical demonstration are central determinants.

To address this gap, district-level agricultural extension services in Babati, in collaboration with local government authorities, research institutions, and relevant NGOs, should establish pilot demonstration plots in representative sloping maize fields. These demonstrations should focus specifically on swale and berm design, contour layout, berm stabilization, outlet construction, and seasonal maintenance. Training should combine classroom instruction with hands-on field-based learning using simple tools such as A-frame levels to ensure farmers acquire practical implementation skills. Participatory approaches such as farmer field schools and peer learning networks may enhance knowledge diffusion and reduce perceived complexity.

Interventions should be evaluated using measurable indicators, including: (i) changes in farmer awareness and adoption rates, (ii) maize yield performance compared with control plots, (iii) soil moisture retention during intra-seasonal dry spells, and (iv) observable reductions in runoff and soil erosion. Monitoring these indicators over multiple seasons would provide robust evidence on the agronomic and economic viability of swales and berms under Babati's bimodal rainfall system, particularly during the high-intensity masika rains (March-April), when harvested water could support maize growth into the drier months (May-July).

While this study did not include direct soil moisture measurements or controlled yield comparisons, it establishes a strong foundation for future experimental trials. Subsequent research should incorporate side-by-side control plots, quantitative soil moisture monitoring, and cost-benefit analysis to rigorously assess the long-term performance of swales and berms. Overall, the findings position this study not only as an assessment of current adoption patterns but also as a practical guideline for strengthening in-situ rainwater management in highland farming systems facing rainfall variability and runoff challenges.

8. Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sampling approach was not fully probability-based, as participants were selected within two villages rather than through district-wide random sampling; therefore, results may not be generalizable to all maize farmers in Babati District or beyond. Second, key variables such as technology use and maize yields were self-reported, which may introduce recall bias or reporting inaccuracies. Third, the study did not include direct biophysical measurements such as soil moisture monitoring, runoff quantification, or hydrological assessments, limiting the ability to empirically validate the agronomic performance of specific RWHTs. Finally, the cross-sectional design captures adoption patterns at a single point in time and does not allow for analysis of longitudinal adoption trends or seasonal dynamics. Future research incorporating randomized sampling, objective yield and soil moisture measurements, and multi-season monitoring would strengthen causal inference and provide more robust evidence on the long-term impacts of swales, berms, and other soil moisture conservation practices.

9. Declarations

9.1 Ethical Approval

This study was conducted in compliance with national and institutional research ethics standards. Ethical approval was obtained from KNCHREC, which is a zonal ethics body comprising the Kibong'oto Infectious Diseases Hospital (KIDH), The Nelson Mandela African Institution of Science and Technology (NM-AIST), and the Centre for Educational Development in Health, Arusha (CEDHA). The Proposed Research, (Research Proposal No: KNCHREC/0002/02/2025) was issued on 8th March 2025. In addition, field research activities were approved by the Babati District Council, which issued an official introduction and authorization letter dated 3 December 2024, permitting the researcher to conduct fieldwork and experimental activities in Ayalagaya Ward. The study adhered to ethical guidelines ensuring respect for participants, communities, and the environment. Informed consent was obtained from all participants prior to data collection. Participation was voluntary, and respondents were assured of confidentiality and anonymity.

9.2 Consent to Participate

Informed consent was obtained from all participants prior to data collection. Participants were informed about the purpose of the study, and their participation was entirely voluntary. They were assured of confidentiality and their right to withdraw from the study at any time without any consequences.

9.3 Consent to Publish

Participants were informed that the data collected would be used for academic and publication purposes. All data have been anonymized to ensure that no individual respondent can be identified.

9.4 Data Availability Statement:

The dataset generated and analyzed during the current study is available in the Zenodo repository at: https://doi.org/10.5281/zenodo.19229456. The dataset includes the guide for questionnaire, FGDs, documentary review and observation. Additional data supporting the findings of this study are available from the corresponding author upon reasonable request.

9.5 Field experiment approval:

Field experimental activities were officially authorized by the Babati District Council, as per the letter issued on 3 December 2024, permitting research activities in Ayalagaya Ward in privately owned fields. The approval covered field observations and on-site assessments of rainwater harvesting structures, as well as engagement with local farmers for data collection and technology demonstration.

Funding: This research was sponsored by Inter-University Council for East Africa (IUCEA), with funding from the World Bank through the Eastern and Southern African Higher Education Centers of Excellence Additional Financing (ACE AF II) Project.

Acknowledgment: We would like to acknowledge the District Executive Director for Babati District Council for permitting us to conduct this study in Babati district. We also acknowledge all the extension staffs, leaders and farmers who participated in the study.

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