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Original article

A descriptive cross-sectional survey on the determinants of adoption of small-scale irrigation technologies for drought resilience among smallholder farmers in Masheruka Sub-County, Sheema District

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Abstract
Background
Despite the availability of irrigation technologies and supportive policy frameworks in Uganda, existing efforts have not scaled as expected among smallholder farmers. This is largely due to a complex interplay of socio-technical constraints. This study analyzed the determinants influencing the adoption of small-scale irrigation technologies for drought resilience among smallholder farmers in Masheruka Sub-County, Sheema District.

Methodology
The study employed a descriptive cross-sectional research design, and primary data were collected from 300 respondents. The study used a questionnaire and a focus group discussion guide to collect primary data. The data were analysed using SPSS version 26.0.

Results
Based on the study results, farm income shows a highly significant relationship ($p = 0.000$). Extension services significantly enhance adoption by providing technical guidance at ($\chi^2 = 48.92$, $p < 0.000$), the results show that age of the farmer ($p = 0.046$), education level ($p = 0.003$), farm size ($p = 0.007$), market access ($p = 0.001$), access to credit ($p = 0.003$), access to extension services ($p = 0.002$), access to reliable water source ($p = 0.001$), perceived technology complexity ($p = 0.012$), significantly influenced the adoption of smallscale irrigation technology and land topography ($p = 0.528$) had no significant relationship.

Conclusion
The study concludes that, while the strong presence of highly aware and knowledgeable farmers indicates a readiness for technological transition, the large middle group of farmers who are aware reveals a critical gap in practical, hands-on training. Ultimately, achieving widespread drought resilience will require moving beyond general awareness campaigns toward targeted, technical extension services that empower the unskilled and bridge the gap for those left behind.

Recommendations
The study recommends shifting from advertising to hands-on training, leveraging peer-to-peer learning, training local technicians should be trained, and establishing affordable spare parts markets should be established alongside the technology rollout.

Keywords: *Small-scale irrigation technologies, drought resilience, regression analysis*
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Introduction
Climate variability and prolonged dry spells have increasingly threatened smallholder farming systems, making irrigation a critical adaptation strategy in Uganda. Despite policy efforts to promote irrigation under national agricultural development frameworks, adoption remains limited among smallholder farmers due to a combination of socio-economic and institutional constraints (Journal of Arid Environments, 2020). High initial investment costs, limited access to credit, inadequate extension services, and insufficient technical skills are among the key barriers hindering uptake (Mango et al., 2018; Serote et al., 2021). Additionally, farmers' perceptions of risk, awareness of climate change, and access to information play a crucial role in influencing adoption decisions (Ogundeji & Okolie, 2022). These socio-technical challenges suggest that increasing adoption requires not only improving access to technologies but also strengthening institutional support systems and enhancing farmer capacity.

In the specific case of Masheruka Sub-County in Sheema District, the adoption of small-scale irrigation technologies reflects localized interactions between socio-economic realities and technological opportunities. Smallholder farmers in this area often face constraints such as limited financial capital, small and fragmented landholdings, and unreliable access to water resources, which directly affect their ability to adopt irrigation technologies (Mume et al., 2023). Social factors including education levels, household labor availability, risk perception, and participation in farmer groups interact with technical factors such as the availability of irrigation equipment, proximity to water sources, and suitability of technologies to local conditions (Eshetu & Mekonen, 2024). Institutional support, including extension services, government programs, and interventions by non-governmental organizations, further shapes adoption outcomes by influencing access to information, training, and financial resources (Serote *et al.,* 2023). Given the increasing frequency of droughts in southwestern Uganda, promoting affordable and context-specific irrigation solutions such as treadle pumps, drip irrigation kits, and rainwater harvesting systems offers significant potential to enhance resilience. However, successful adoption will depend on addressing the intertwined socio-technical barriers that limit uptake and ensuring that technologies are tailored to the needs and capacities of local farmers.

Smallholder farmers in Masheruka Sub-County, Sheema District, operate within an increasingly uncertain climatic environment characterized by erratic rainfall patterns, prolonged dry spells, and recurrent droughts that undermine agricultural productivity and household food security. Although small-scale irrigation technologies such as drip systems, treadle pumps, and water harvesting technologies have been promoted globally and nationally as viable climate adaptation strategies, the irrigation innovation adoption in this context remains limited and inconsistent. This creates a critical gap between the current situation, where farmers remain heavily dependent on unreliable rain-fed agriculture, and the desired state of resilient, stable, and sustainable food production systems capable of withstanding climatic shocks (Intergovernmental Panel on Climate Change, 2022). The bulk of existing literature focuses on large-scale, centralized public irrigation schemes (such as Mubuku or Doho) or flat, water-abundant regions (Ogundeji & Okolie, 2022). These studies fail to account for the unique, highly dissected hilly topography, steep slopes, and localized groundwater dynamics of Sheema District, which impose distinct physical and economic pumping constraints on micro-irrigation systems (Susilawati *et al.,* 2025).

Despite the availability of irrigation technologies and supportive policy frameworks in Uganda, existing efforts have not scaled as expected among smallholder farmers. This is largely due to a complex interplay of socio-technical constraints (Mango et al., 2018). Socially, limited awareness and inadequate technical knowledge of new technologies hinder adoption decisions. Technically, poor suitability of some irrigation technologies to local conditions further constrains uptake of small-scale irrigation technologies (Mango et al., 2018). Consequently, the persistence of these barriers prevents the widespread adoption and scaling of irrigation technologies, leaving farmers vulnerable to climate variability and food insecurity. Therefore, there is a need to systematically examine the socio-technical determinants influencing the adoption of small-scale irrigation technologies in Masheruka Sub-County. Understanding how social, economic, institutional, and technical factors interact to shape farmers' decisions is essential for bridging the gap between the availability of irrigation technologies and their effective utilization. Addressing this gap contributes to enhancing drought resilience, improving agricultural productivity, and achieving sustainable food security among smallholder farmers in the study area. Thus, this study analyzed the determinants influencing the adoption of small-scale irrigation technologies for drought resilience among smallholder farmers in Masheruka Sub-County, Sheema District. The specific objective of this study was to examine the socio-economic and technical factors influencing the adoption of small-scale irrigation technologies among smallholder farmers.

Materials and Methods

Study duration

The study started on 5th, January, 2026 and ended on 15th, August, 2026.

Study area

The study was conducted in Masheruka sub-county, Sheema district. It lies between the coordinates of approximately 0.3975°S latitude and 30.4175°E longitude. Sheema District experiences a bimodal rainfall pattern, with two main rainy seasons: March to May and September to November. The average annual rainfall ranges from 1,200 mm to 1,800 mm, making it one of the wetter regions in Uganda. However, the distribution of rainfall can be erratic, leading to challenges in agricultural planning and production (Nimusiima *et al.,* 2022).

The district has a moderate climate with average temperatures ranging between 18°C and 25°C. The high-altitude areas tend to be cooler, particularly during the rainy seasons, while the lowland areas can experience slightly warmer temperatures.

Sheema's soils are generally fertile, supporting a variety of crops including smallholder crops, bananas, and coffee. However, the hilly terrain makes the area prone to soil erosion, especially during heavy rains. The vegetation is primarily a mix of tropical rainforest in the valleys and savannah grasslands on the higher slopes. The district was chosen for this study on adoption of micro-scale irrigation technologies because it had significant agricultural potential due to its fertile soils and favorable climate. However, the hilly terrain and the erratic distribution of rainfall posed challenges to consistent agricultural production. These factors made the district an ideal location to study the adoption of a micro-scale irrigation program, which helped mitigate water-related challenges and enhance smallholder productivity.

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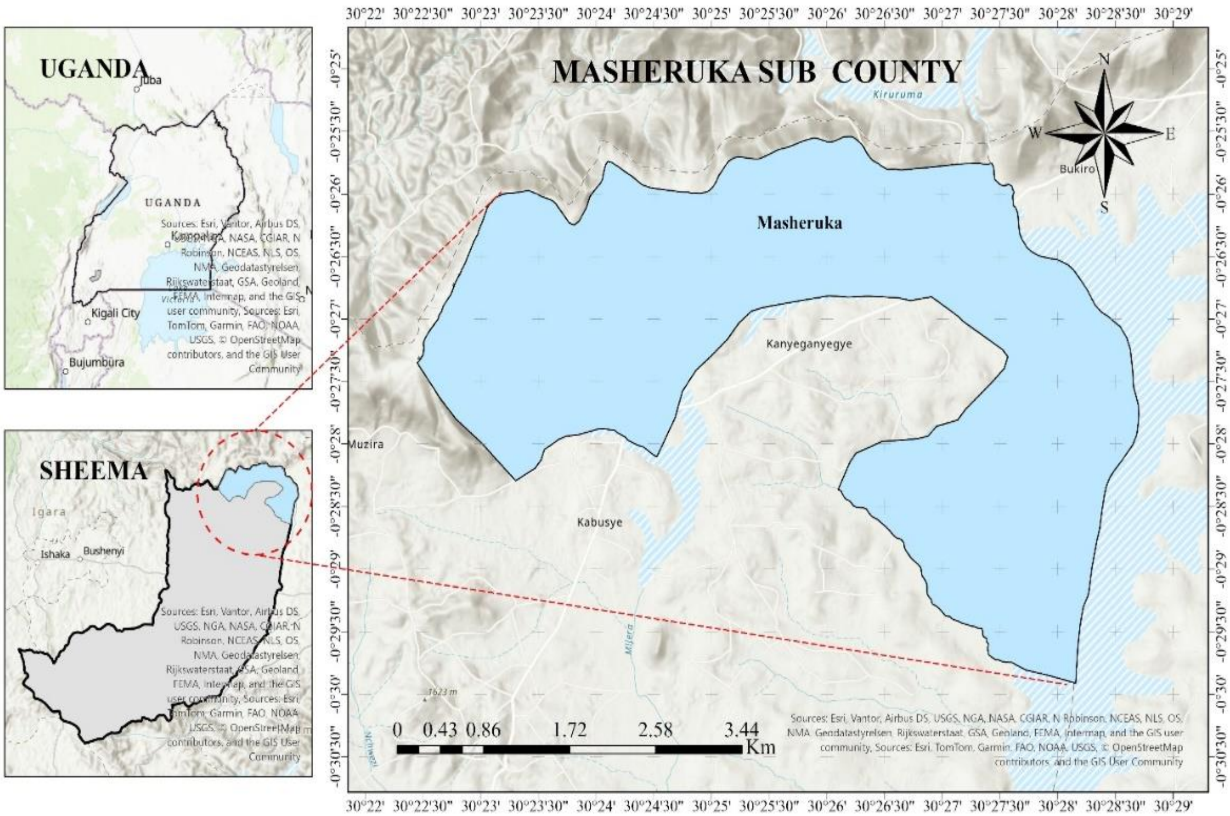

Figure 3.1: Location of the study area

Research design

The study adopted a descriptive cross-sectional survey, which allowed the study to collect data at a single point in time from a sample that represents the entire population of smallholder farmers in Masheruka Sub-County. This design was ideal for understanding the current status of micro-scale irrigation adoption and the factors influencing it. The snapshot provided by this approach is valuable for capturing the adoption rates and identifying key barriers. The descriptive nature of the design enabled the collection of both quantitative and qualitative data. Quantitative data were gathered through structured questionnaires that measured the extent of adoption, the characteristics of the farmers, and the economic, social, and environmental factors influencing their decisions. Qualitative data were obtained through interviews or focus group discussions, which provided deeper insights into the perceptions, attitudes, and experiences of the farmers regarding micro-scale irrigation. The design was deemed appropriate because, given that Masheruka Sub-County likely had a significant number of smallholder farmers, the cross-sectional survey design was efficient for studying large populations.

Study population

The study targeted smallholder farmers, extension agents, and community stakeholders.

Eligibility criteria

Inclusion criteria

To participate in the study, individuals met all of the following conditions:

Respondents were currently residing and operating a farm within Masheruka sub-county, Sheema District. Must qualify as a smallholder farmer (typically defined by cultivating less than 2 to 5 acres of land, depending on local standards. Must be engaged in crop production that is vulnerable to seasonal droughts or water scarcity. They were willing to provide voluntary written or verbal informed consent to participate.

Exclusion criteria

Large-scale commercial farmers who operated highly mechanized systems or held extensive land acreage were excluded.

Farmers who owned land in Masheruka sub-county but resided and managed operations remotely from other

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districts or urban centers were excluded. Newly established households with less than one full farming season of experience in the area were excluded.

Bias

Randomizing at the cluster level (for example, at village level) and varying the saturation rate of adoption within clusters to explicitly measure and adjust for spillover effects. Collecting geographic coordinate data for all surveyed households to model spatial decay and account for proximity to adopters during econometric analysis. Ensuring gender-balanced or female-led farming households were explicitly powered and represented in the sampling design. Implementing rigorous tracking protocols to follow migrating households and providing adequate compensation for time during follow-up surveys was emphasized.

Sampling procedure

The study targeted smallholder farmers and key informants like extension service providers and community-based facilitators. A multi-stage stratified random sampling technique was used to select sample smallholder farmers. Mashuruka subcounty was considered in this study. Within the subcounty, each of the parishes in the subcounty was purposively selected. Then the farmers in each selected village were stratified into two groups as participants and non-participants of the agricultural extension training services. The groups were identified from a list of agricultural extension workers, and then the information was confirmed by the farmers. Second, the two groups obtained from the first-stage sampling were further stratified into male- and female-headed households to ensure, as much as possible, representation of female-headed households in the sample.

A purposive sampling method was used in the selection of key informants. The key informants were considered for their technical knowledge, advisory services, and policy implementation, and provided supplementary information that might not be provided by other respondent categories.

Sample size determination

The sample size was determined by Kish's (1965) formula. According to the formula, the sample size was determined with some degree of precision for the general population used.

The sample size was determined by Kish and Leslie's (1965) formula, depending on the degree of precision of the general population used.

$n = pq\,[Z/e]^2$

Where: n will be the sample size; p = population proportion of key informants (30%), q = smallholder farmers population proportion (65%); e = marginal error (5%); and Z= Z value of 95% confidence from the Z-table (1.96)

$0.3 \times 0.65\,(1.96/0.05)^2$

n = 300 respondents

Data collection method

The study chose the primary quantitative data collection method to gather standardized, numeric data from individual smallholder farmers, who served as the core unit of analysis in this study. This method was physically executed by trained research assistants who visited sampled households across Masheruka Sub-County, conducting face-to-face interviews to minimize non-response rates and overcome any potential literacy barriers among older or less-educated farmers. This was applied to smallholder farmers only. The focus group discussion method was employed as a qualitative strategy to capture community consensus, shared social dynamics, and collective behavioral patterns. To prevent social dominance and ensure uninhibited expression, these groups were deliberately separated into homogeneous cohorts, such as distinct groups for female key informants, youth key informants, technology adopters, and non-adopters.

Data collection tools

A structured questionnaire with both open-ended and closed-ended questions was ideal for gathering a wide range of data from smallholder farmers in Masheruka Sub-County. The closed-ended questions allowed for the collection of quantitative data that can be easily analyzed to identify patterns and correlations. These included questions on the extent of micro-scale irrigation adoption, access to resources, and demographic information.

A semi-structured focus group discussion guide was used as it allowed for in-depth exploration of group dynamics and collective attitudes towards micro-scale irrigation among smallholder farmers. Focus group discussions were particularly useful in understanding how social, cultural, and communal factors influence the adoption of new technologies like micro-scale irrigation. The semi-structured nature of the focus group discussion guide ensured that key topics were covered while allowing participants the flexibility to discuss issues that were most relevant to them. This format encouraged rich discussions, as participants could build on each other's ideas, providing deeper insights than individual interviews might reveal.

Reliability and validity of the instruments

Prior to the actual data collection process, the survey instruments were subjected to pilot testing to determine reliability and validity. A semi-structured questionnaire was administered to selected respondents in Masheruka sub-county, Sheema district, who were later excluded from the main survey. The Cronbach's alpha coefficient was 0.78, indicating acceptable reliability of the instrument. Validity was assessed by experts in small-scale irrigation technologies, whose contributions helped refine the questions and improve the instrument.

Ethical approval

The study was ethically approved by the Bishop Stuart University Research Ethics Committee. The ethical clearance number is BSU-REC-2026-2190, and the approval date was 6th, July, 2026.

All participating respondents were adequately informed about the research objectives, methods, and potential implications before their voluntary informed consent was obtained. Care was taken to protect participants' confidentiality and anonymity. Given the study's socio-economic implications, the study avoided potential sources of bias and ensured fair treatment of all respondents. All respondents provided verbal consent to participate in the study.

Data analysis

Quantitative data analysis involved the use of statistical techniques to analyze numerical data collected through surveys and group discussions.

Statistical Package for the Social Sciences (SPSS) was used to analyze quantitative data to generate descriptive statistics, which were used to summarize the adoption of the micro-scale irrigation program. Inferential statistics were also generated to make inferences about a population based on a sample. Techniques such as descriptive and regression analysis were used to compare adoption and small-scale irrigation technologies among farmers.

Study results

Participants flow

Below is a structured report featuring a standard participant flow layout and descriptive numbers tailored for a study on Determinants of Adoption of Small-Scale Irrigation Technologies for Drought Resilience among Smallholder Farmers in Masheruka Sub-County, Sheema District.

Detailed breakdown of participant flow stages

Potentially eligible

390 smallholder farming households.

Sourced from local administrative registers and parish lists in Masheruka Sub-County, Sheema District.

Reasons for non-participation: 40 households were excluded before screening:

25 households had migrated or transitioned out of crop farming.

15 households resided in geographically isolated areas unreachable within the survey schedule.

Examined for eligibility (Screened)

350 smallholder farming households.

Households assessed against inclusion criteria (active smallholder farming status, reliance on rain-fed systems, and vulnerability to dry spells).

Reasons for non-participation: 32 households were disqualified or dropped out during screening:

12 households lacked the continuous agricultural land required for small-scale irrigation adoption.

20 households declined to provide informed consent due to time constraints or skepticism regarding surveys.

Confirmed eligibility

318 smallholder farming households.

Households that successfully cleared all inclusion thresholds and agreed conceptually to participate.

Included in the Study (Enrolled).

310 smallholder farming households.

The final baseline sample was targeted to ensure the final analyzed cohort met statistical power requirements.

Reasons for non-participation: 8 eligible households were uncontactable before baseline questionnaires could be administered.

Completed Follow-Up

300 respondents.

Participants who completed all waves of data collection (interviews, questionnaires, and validation checks).

Reasons for Attrition: 10 participants were lost before study completion:

6 households migrated permanently out of Masheruka Sub-County.

4 household heads experienced prolonged health issues or were unavailable during final validation sweeps.

Analyzed 300 complete respondents.

The final clean sample size of 300 was utilized for econometric modeling and statistical analysis of adoption determinants.

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Flow diagram

(Potentially Eligible Smallholder Farming Households)
(N = 390 registered in Masheruka Sub-County)

Excluded before screening (n = 40)
Inaccessible due to remote terrain (n = 15)
Out-migration/no longer farming (n = 25)

(Households Examined for Eligibility)
(n = 350)

Excluded during screening (n = 32)
Failed to meet minimum farming criteria (n = 12)
Declined to participate/ refused (n=20)

(Confirmed Eligible Participants)
(n = 318)

Lost/Not included due to logistical constraints (n = 8)

(Included in the Study Sample)
(n = 310)

(Completed Follow-up) (Lost to Follow-Up / Drop-outs)
(n = 300) (n = 10)

Moved out of sub-county (n = 6)
Severe illness/incapacitated (n = 4)

(Included in Final Data Analysis)
(n = 300)

The resulting dataset was subjected to statistical analyses, including descriptive statistics and regression, to examine the socio-economic and technical factors influencing the adoption of small-scale irrigation technologies among smallholder farmers.

Table 1: Demographic and Socioeconomic Characteristics (n=300)

Variable	Category	Frequency (n)	Percentages (%)
Respondent's sex	Female	136	45.3
	Male	164	54.7
Age distribution	< 30 years	56	18.7
	31–40 years	72	24
	41–50 years	84	28
	51–60 years	49	16.3
	61 & above	39	13
Marital status	Single	26	8.7
	Married	235	78.3
	Widowed	31	10.3
	Divorced	08	2.7
Level of education	No formal education	24	8.0
	Primary	144	48.0
	Secondary	99	33.0
	Post-secondary	33	11.0
Farming experience	< 1 year	19	6.3
	2–3 years	37	12.3
	4–5 years	50	16.7
	6–7 years	57	19.0
	> 8 years	137	45.7
Cultivated land size	Less than an acre	81	27.0
	1–2 acres	121	40.3
	2-3 acres	58	19.3
	3-4 acres	22	7.3
	5 acres and above	18	6.0

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Table 1 shows a relatively balanced gender distribution, with a slight male majority: 54.7% male and 45.3% female. The age distribution shows that 18.7% are under 30 years, 24.0% are aged 31–40, 28.0% are aged 41–50, 16.3% are aged 51–60, and 13.0% are 61 years or older. A large majority of the respondents are married (78.3%), followed by widowed individuals 10.3%, single individuals 8.7%, and divorced individuals 2.7%. Results in Table 1 reveal that 8.0% of farmers have no formal education, 48.0% have attained a primary level, 33.0% have reached a secondary level, and 11.0% possess post-secondary qualifications. Regarding experience, the study results indicate that only 6.3% have less than a year of experience, 12.3% have 2–3 years, 16.7% have 4–5 years, 19.0% have 6–7 years, and 45.7% have more than 8 years of experience. This indicates a highly experienced farming community, with nearly two-thirds (64.7%) having farmed for over 6 years. The land size distribution shows that 27.0% cultivate less than an acre, 40.3% farm on 1–2 acres, 19.3% farm on 2–3 acres, 7.3% manage 3–4 acres, and only 6.0% own 5 acres or more.

Table 2: Binary logistic regression output for Socio-economic and technical factors influencing the adoption of small-scale irrigation technologies among smallholder farmers

Variable	Variable name	Coefficient (β)	Std. Error (SE)	p-value	Odds Ratio (Exp(β))
Socio-economic	Age of farmer	-0.042	0.021	0.046	0.959
	Education level	0.450	0.150	0.003	1.568
	Farm income	0.810	0.220	0.000	2.248
	Farm size	0.380	0.140	0.007	1.462
	Market access	0.740	0.230	0.001	2.096
	Access to credit	1.050	0.350	0.003	2.858
	Extension services	0.920	0.290	0.002	2.509
Technical	Access to water Source	1.380	0.420	0.001	3.975
	Technology complexity	-0.580	0.230	0.012	0.560
	Land topography	-0.120	0.190	0.528	0.887

Age of the farmer (p = 0.046): Significant relationship
The negative coefficient (beta = -0.042) shows that older farmers are less inclined to adopt. With each added year of age, the likelihood of adopting irrigation drops to 0.95 times.
Education level (p = 0.003): Significant relationship
Highly significant and positive. A higher level of formal education increases the odds of irrigation technology adoption by 1.57 times, likely because educated farmers process technical information and assess climate risks more effectively.
Farm income (p = 0.000): The results show a highly significant relationship. Wealthier households are 2.25 times more likely to adopt these technologies, as they can comfortably absorb the high initial start-up and maintenance costs.
Farm size (p = 0.007): Farm size has a positive and highly significant relationship with adoption. For every additional hectare of land a farmer owns, the odds of adopting small-scale irrigation technologies increase by 1.46 times. Farmers with larger tracts of land have more space to justify the capital investment and can achieve better economies of scale.
Market access (p = 0.001): significant relationship
Market access is a powerful, positive driver. Farmers with reliable market access are 2.10 times more likely to adopt irrigation. When smallholders know they can easily sell their surplus dry-season crops for a profit, they are much more willing to invest in irrigation infrastructure.
Access to credit (p = 0.003): Significant relationship
Smallholders with access to agricultural loans or credit lines are 2.86 times more likely to adopt irrigation compared to credit-constrained farmers.
Access to extension services (p = 0.002): Significant relationship
Regular contact with extension agents increases the odds of adoption by 2.51 times. Institutional training builds the capacity needed to manage small-scale systems confidently.
Access to reliable water source (p = 0.001): Significant relationship
Remaining the strongest overall predictor, reliable water proximity increases the odds of adoption by 3.98 times. Proximity to a steady water source is the foundational technical prerequisite for any small-scale irrigation technology project.
Perceived technology complexity (p = 0.012): Significant relationship
The negative coefficient (beta = -0.580) confirms that if a technology is perceived as difficult to set up, operate, or fix, the odds of adoption fall by 0.56 times.
Land topography (p = 0.528): No significant relationship

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Because the p-value is much greater than 0.05, the slope or terrain of the land does not statistically influence a farmer's decision to adopt irrigation technology.

Qualitative findings

In another discussion conducted with an extension officer about major knowledge gaps or misunderstandings among farmers regarding irrigation technologies, it was revealed that *"Farmers believe that irrigation means 'flooding the soil.' Over-watering causes nutrient leaching and fungal diseases, which they mistake for poor seed quality."*

In another discussion held with local leaders, it was reported that *"Many believe irrigation is only possible if you share a direct boundary with a river or swamp, failing to understand water harvesting or pumping uphill."*

In another discussion held with extension officers *on* how *knowledge* gaps affect farmers' willingness or ability to adopt, it was reported that *"Farmers fear breaking expensive systems they don't understand, so they choose to stick to traditional, low-yield rain-fed farming."*

In a discussion held with a subcounty extension officer on the level of awareness of small-scale irrigation technologies among farmers, it was reported that *"Awareness is moderate on paper but technically shallow. Farmers know irrigation provides water, but they don't understand system flow rates or crop water requirements."*

According to local leaders*, it was* said that *"High awareness of irrigation exists because they see government flyers and wealthy farmers using pumps. However, uphill subsistence farmers feel it doesn't apply to them".*

In another discussion held with extension officers on how awareness has changed over the past few years, it was said that *"It has changed significantly due to worsening droughts and erratic rainy seasons in Sheema District, forcing farmers to seek climate-smart alternatives."*

According to local leaders, it was reported that *"It has increased because the government has actively promoted co-funding schemes for irrigation over the last 3-4 years."*

Discussion of results

The binary logistic regression results provide clear insights into the specific socio-economic and technical forces that either drive or block smallholder farmers from adopting small-scale irrigation technologies. The model evaluated ten distinct variables, and the statistical results reveal that nine of these factors heavily dictate a farmer's decision-making process. By looking at the coefficients, p-values (which tell us if a result is meaningful), and Odds Ratios (which show the likelihood of adoption).

Education level has a highly significant, positive influence on the adoption of small-scale irrigation technologies (beta = 0.450, p = 0.003). With an odds ratio of 1.568, the model indicates that for every incremental increase in a farmer's formal education level, the probability of adopting irrigation increases. The result further revealed that higher education levels significantly boost a farmer's willingness to participate in and pay for improved irrigation infrastructure due to a clearer understanding of resource sustainability.

This result mirrors the findings of Ayim *et al.* (2020), who noted that education enhances farmers' ability to process information, understand technical instructions, and evaluate the costs and benefits of irrigation technologies. Literate farmers are more likely to engage with extension services, interpret training materials, and experiment with new technologies.

The study results revealed that farm size exerts a positive and statistically significant effect on adoption behavior (beta = 0.380, p = 0.007). The odds ratio of 1.462 signifies that as landholdings expand, the likelihood of adopting irrigation increases by 46.2%. Larger farms permit more cost-effective distribution of pipes and canals, lowering the per-unit cost of irrigation. Additionally, smallholders with larger plots can afford to dedicate portions of land to experimental, high-value irrigated crop production without compromising their core subsistence farming. This finding matches the findings of Muthui (2024), who argued that farmers with larger and more secure landholdings are more likely to invest in irrigation because they can achieve higher returns and have long-term control over their land.

Market access is revealed to be a highly significant driver of irrigation technology adoption (beta = 0.740, p = 0.001). The odds ratio of 2.096 dictates that farmers with reliable market access are over two times more likely to invest in small-scale irrigation. The logic behind this mechanism is rooted in commercialization; irrigation allows for off-season cultivation and high-volume yields of perishable crops (like vegetables and fruits). However, these benefits are only realized if a farmer can swiftly move products to market before spoilage occurs.

This finding is consistent with Okurutu & Banda (2010), who highlighted that proximity to transportation networks and active market hubs lowers transaction costs, creating a powerful economic pull factor for technology adoption. When market linkages are broken, farmers face high crop-failure risks in the form of post-harvest economic loss, which disincentivizes them from investing in yield-enhancing technologies in the first place.

Access to a reliable water source is the strongest and most statistically significant predictor in the entire regression model (beta = 1.380, p = 0.001). The massive odds ratio of 3.975 establishes that smallholders with a secure water source are roughly four times more likely to adopt irrigation technologies. This represents a fundamental physical prerequisite: regardless of a farmer's income, education, or willingness to innovate, an irrigation system cannot function without accessible surface or groundwater.

This finding concurs with findings of the FAO report (2020), which reported that irrigation technologies depend on consistent access to water, whether from rivers, streams, boreholes, or rainwater harvesting systems. In areas where water sources are unreliable or seasonal, farmers may be

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reluctant to invest in irrigation technologies due to uncertainty about their effectiveness. This is particularly relevant in Sheema District, where rainfall variability affects water availability. Access to technical knowledge and training is also a key determinant of adoption. Farmers need practical skills to operate irrigation systems, manage water efficiently, and perform routine maintenance.

The study results show that contact with extension services is highly significant and positively influences the adoption process (beta = 0.920, p = 0.002). The odds ratio of 2.509 implies that regular interaction with agricultural extension officers makes a farmer 2.51 times more likely to implement irrigation. Extension agents serve as the primary institutional channel for knowledge transfer in rural areas. They demystify new tools, offer hand-holding during early installation phases, and communicate best practices regarding crop water requirements, thereby reducing a farmer's psychological fear of technology failure.

This finding is comparable to Melaku and Molla (2025), who confirmed that frequent extension contacts drastically boost a farmer's managerial capabilities and willingness to pay for improved systems. Likewise, contemporary climate adaptation research views extension delivery networks as a foundational pillar for building long-term rural resilience, as it shifts the farmer's mindset from passive rain-dependence to proactive water management.

The analysis reveals that farm income is an exceptionally powerful and statistically significant predictor of irrigation technology adoption (beta = 0.810, p = 0.000). The corresponding odds ratio of 2.248 shows that higher-income farmers are more than twice as likely to adopt small-scale irrigation compared to their lower-income counterparts. Small-scale irrigation technologies, whether drip systems, motorized pumps, or solar-powered setups, require substantial initial capital investments for procurement, transportation, and installation. Higher farm incomes alleviate these immediate liquidity constraints, giving wealthier smallholders the financial buffer to take risks.

Generalizability

The statistical relationships identified in the study, such as the strong predictive power of water source proximity, access to credit, farm income, and extension services, exhibit strong internal validity and align closely with wider adoption literature across Sub-Saharan Africa. Therefore, these findings can be generalized to smallholder farming communities in Uganda (and neighboring East African countries) that share similar structural characteristics, such as rain-dependent agriculture, fragmented land holdings, and developing rural market infrastructure. The findings possess moderate-to-high analytical generalizability regarding behavioral and economic catalysts (finance, water proximity, institutional support) for smallholder irrigation. However, they possess low demographic generalizability to commercialized, large-scale farming sectors or vastly different agro-ecological zones. Policy interventions should use these insights as a baseline while tailoring implementation to local infrastructural realities.

Conclusion

The study concludes that adoption of small-scale irrigation technologies is heavily dictated by both economic feasibility and technical empowerment. Financial constraints, specifically liquidity and investment capacity, are the primary determinants of adoption**.** However, for irrigation technologies to be sustainably integrated, financial interventions must be paired with technical guidance and user education.

Limitations of the study

The study sample was not representative of the broader population, leading to sampling bias. For example, if the sample was drawn from a specific demographic group or geographic region, the findings might not be generalizable to other populations.

The study might not have had adequate funds to cover transport, stationery requirements, and secretarial services.

The validity and reliability of measurement instruments were compromised, leading to biased or inconsistent results. The study assessed the validity and reliability of its measures and addressed any limitations through pilot testing and validation procedures.

Low response rates or non-response bias: Such bias in this survey-based research affected the representativeness of the sample and introduced bias into the findings.

Recommendations

Shift from advertising to hands-on training: Agricultural extension officers and NGOs should move away from broad radio or poster campaigns. Instead, they should launch practical, field-based "how-to" workshops tailored for the large middle group of farmers who are aware of the technology but lack the technical skills to operate and maintain it.

Governments and development partners must intentionally target geographically isolated and marginalized areas to reach the 15% of farmers who are completely unaware. Initial interventions here should focus on basic exposure, such as setting up local demonstration plots.

Leverage peer-to-peer learning: The 26.7% of farmers who are already "Highly Aware and Highly Knowledgeable should be recruited as lead farmers/model farmers. By training their neighbors and demonstrating their own success, they can drive low-cost technology adoption throughout the community.

Provide post-adoption support: To prevent farmers from abandoning the technology due to technical failures (like clogged pipes or pump breakdowns), local technicians should be trained, and affordable spare parts markets should be established alongside the technology.

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Launch targeted sensitization campaigns using local radio, mobile SMS alerts, and community workshops. These campaigns should demystify irrigation technology, shifting the perception of irrigation from being a luxury to an accessible climate-resilience asset.
Train village technicians: Build local capacity by training youth or lead farmers in basic maintenance and operational handling. This ensures that when technical issues arise, farmers have immediate, affordable local support to prevent system abandonment.
Governments and NGOs should offer targeted, smart subsidies on high-cost components (such as solar pumps or drip kits). Additionally, establishing local spare-parts hubs can reduce recurring maintenance costs.

List of abbreviations

BSU-REC: Bishop Stuart University Research Ethics Committee
Dr: Doctor
FAO: Food Agricultural Organisation
NGOs: Non-governmental Organisations
Rev: Reverend
SPSS: Statistical Package for Social Sciences

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Availability of data

The data are available upon reasonable request from the corresponding author.

Author's contribution

Perez Tayebwa: Conceptualization, investigation, data collection, analysis, writing the original report draft, and visualization.
Rev. Dr. Gershom Nuwemuhwezi: Supervision, Validation, Review & Editing.
DR. Mr. Wesiga Jimmy: Supervision, review & editing.

Author's biography

Rev. Dr. Gershom Nuwemuhwezi is a Senior Lecturer, researcher, and ordained Reverend at Bishop Stuart University. He teaches subjects including entomology, nutrition, and food value addition, and coordinates research in science education. He holds a PhD in Food Security and Sustainable Agriculture from JOOUST, with research interests spanning entomophagy, aquaculture, and sustainable agriculture.
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Conflict of interest

The authors declare no conflict of interest.

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