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Determinants of farmers' use of small-scale irrigation practice in the *Achewa* area, Gambella, Southwestern Ethiopia

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Abstract

Small-scale irrigation (SSI) has emerged as a vital strategy for enhancing food security, increasing agricultural productivity, and building resilience to climate change. This study examined the determinants of SSI use among farmers in the Achewa area, Gambella, Southwestern Ethiopia. A cross-sectional research design was employed, using a two-stage stratified random sampling approach to select 294 household heads (192 irrigation users and 102 non-users). Data collection involved household surveys, focus group discussions, and key informant interviews. Binary logistic regression analysis identified several significant factors affecting the adoption of small-scale irrigation (SSI). Notably, male-headed households were 12.85 times more likely to adopt SSI than female-headed households, underscoring a marked gender disparity in adoption patterns. Access to credit increased the likelihood of SSI use by 2.98 times, while access to training raised it by 4.64 times. Larger livestock holdings (measured in Tropical Livestock Units) were associated with a 1.60 times higher probability of SSI use. Additionally, households with higher education levels and larger family sizes were more likely to be SSI users, with education and family size positively influencing adoption. These findings emphasize the importance of targeted interventions to promote equitable access to training and financial resources, particularly for female-headed households. Policies should prioritize empowering marginalized groups, such as female-headed households and older farmers, to enhance the adoption of small-scale irrigation (SSI). By addressing the barriers they face, these policies can expand SSI use, improve agricultural productivity, and uplift rural livelihoods in the region.

Keywords: Achewa, Binary Logistic regression, Farmers, Non-users, Small-scale irrigation, Community attitude

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1. Introduction

Small-scale irrigation (SSI) has become a pivotal approach around the globe for tackling food scarcity, enhancing agricultural efficiency, and building resilience against climate change (Asfaw Eshetu & Mekonen, 2024; Daru & Alemu, 2024). Irrigated farming contributes to approximately 40% of global crop yields, despite covering only about 20% of the total arable land, highlighting its significant role in food production (Mume et al., 2023). Studies indicate that SSI can increase the yields of key crops like wheat and maize by 20–35% when optimal conditions are met, particularly when combined with effective water management practices (Wang et al., 2021). Nevertheless, the implementation of SSI varies greatly across regions, facing obstacles such as economic water shortages, inadequate infrastructure, and socio-economic challenges, including limited access to financing, land ownership disputes, and weak institutional frameworks (Daru & Alemu, 2024; Wang et al., 2021). Overcoming these hurdles is essential for reducing the yield disparity and promoting sustainable food systems (Fissahaye et al., 2023; Nakawuka et al., 2018).

The Ethiopia Ten-Year Development Plan (2021–2030) focuses on reducing reliance on rainfall by promoting small-scale irrigation (SSI) through public-private partnerships, enhanced planning, and private sector engagement. (Wolka et al., 2023; Zeleke et al., 2024). Recent studies have highlighted the positive impacts of SSI on productivity, income, and resilience across various Ethiopian regions. For instance, in the Koga and Fogera irrigation schemes, households employing SSI have reported significant increases in crop yields, household income, and food security compared to non-users (Tsegaye et al., 2025). In North Wollo's Gubalafto district, users of SSI have noted greater crop diversity, increased income, and asset accumulation, despite challenges related to input costs, water scarcity, and transportation (Alemu et al., 2022). Similar findings in Offa Woreda, Wolaita Zone, indicate that small-scale irrigation (SSI) has significantly contributed to poverty reduction through enhanced production and consumption stability (Tsegaye et al., 2025). However, the adoption of small-scale agricultural practices is influenced by various socio-economic, institutional, and environmental factors (Girma et al., 2025; Haile et al., 2024; Zeleke et al., 2024).

The factors influencing the adoption of SSI have been investigated using quantitative modeling techniques. For example, a study in Southern Ethiopia (2022) employed a Tobit model to examine key determinants of small-scale irrigation adoption, including the gender, age, and education level of household heads, annual household income, access to information and extension services, and proximity to water sources (Girma et al., 2025). Another meta-analysis study conducted by Girma et al. (2025) in Ethiopia revealed that adopting irrigation technologies is very low (4.7%) compared with the country's massive potential. In addition, different scholars have identified consistent drivers of SSI adoption, including education, landholding size, access to credit, frequency of extension contact, proximity to water sources, age, livestock ownership, and agro-ecological conditions (Abegunde et al., 2020; Tariku & Kebede, 2024); (Abegunde et al., 2020). Findings suggest that younger, more educated farmers with better access to institutions tend to adopt SSI at higher rates, while older and less resourceful households often lag behind Tariku & Kebede, 2024). Small-scale irrigation and better soil management can support climate change adaptation in the study area, but evidence on their effectiveness for household resilience and farmers' perceptions remains limited.

The Gambella region of Ethiopia possesses substantial irrigation potential owing to its abundant surface and groundwater resources, fertile alluvial soils, and favorable topography. Major rivers such as the Baro, Akobo, Gilo, and Alwero, together with numerous tributaries and wetlands, provide reliable year-round water supplies suitable for irrigation development. According to the Ministry of Water and Energy (Degife et al., 2018), the Baro-Akobo basin represents one of Ethiopia's largest untapped water resources, with significant potential for both small and large-scale irrigation development. Studies further indicate that the region has extensive arable land suitable for irrigation-based agriculture (Awulachew, 2019) Using this substantial potential, smallholder farmers in the study area have benefited from small-scale irrigation by increasing cropping intensity, which in turn has contributed to improved living standards. However, some households remain hesitant to participate in irrigation schemes that rely solely on rainfed agriculture, as the resulting output is often insufficient to meet household food needs. The underlying reasons for this low participation are not yet clearly identified or well understood within the Gambella context. Moreover, research on the factors limiting smallholder engagement in small-scale irrigation and its impact on household income remains limited in the study area. In other parts of Ethiopia, several studies have identified key determinants of irrigation use, including profitability, access to inputs, and institutional support (Abegunde et al., 2020; Haile et al., 2024). However, these factors remain largely unstudied in the context of Gambella. Consequently, the socio-economic, institutional, and contextual mechanisms influencing farmers' irrigation decisions remain poorly understood. This gap underscores the urgent need to investigate the determinant factors influencing households' use of small-scale irrigation in the Achewa area of Gambella, southwestern Ethiopia, thereby providing a foundation for evidence-based policies and targeted development interventions.

2. Materials and Methods

2.1. Description of the study area

This study was conducted within the Achewa small-scale irrigation scheme in the Itang Special District of the Gambella region, southwestern Ethiopia, located about 50 km west of Gambella town and 837 km from Addis Ababa (Mengiste et al., 2025). The scheme lies at 8°12′37.97″ N and 34°14′33.91″ E, at an altitude of 440 meters above sea level, with predominantly level to gently sloping terrain (Yeshi Ber, 2003). The area experiences a single rainy season from April/June to October, with peak rainfall in May and October, while February and March are the driest months. Average temperatures during the dry season range from 21.5°C to 39.85°C (Mengiste et al., 2025), and meteorological records from 2010 to 2020 show annual rainfall averaging 1024.9 mm with irregular distribution. Local smallholders depend on both rain-fed and irrigated agriculture but face challenges from seasonal flooding and drought, which threaten crop production and food security (Mengiste et al., 2025; Yeshi Ber, 2003).

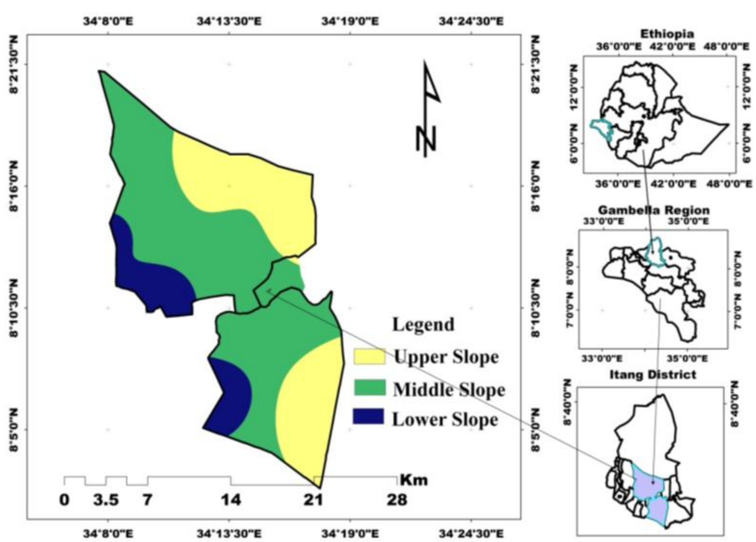

Figure 1 Map of the study area, adopted from (Mengiste et al., 2025)

The study area's geology features sandstone, quartz, and Miocene basalt, layered with Pliocene sediments and Quaternary deposits (Yeshi Ber, 2003). The Gambella region boasts diverse agricultural soils, mainly Vertisols, Fluvisols, and Luvisols, known for their clayey texture and high water retention (Mengiste et al., 2025). According to these authors, soils are rich in organic carbon and nitrogen, benefiting from regular replenishment by alluvial sediments. Additionally, the area contains valuable mineral resources, including gold, copper, and limestone, contributing significantly to Ethiopia's mining sector and economy. Early irrigation initiatives in the region covered a combined area of 1,315 hectares (ha) (Mengiste et al., 2025). Of this, 415 ha were designated for small-scale use, while 900 ha were intended for medium-scale projects. The rivers that supply this area originate in the Ethiopian highlands, with elevations between 2,000 and 3,500 meters, and they flow westward into the Gambella plain, which sits at an elevation of 450 meters.

The projected total population of the Itang special district for July 2017 was 42,000 residents, distributed among 21 Kebele (The smallest administrative division), which are small administrative units (CSA, 2017). Owing to farming activities, many residents live in subsistence conditions, facing food insecurity due to low agricultural productivity linked to traditional farming practices. Farmers primarily use Shella plowing, which conserves soil structure but limits cultivation area and yields. Challenges are further compounded by inadequate access to agricultural technology and support services. In Itang Special District, smallholder farmers engage in both rain-fed and irrigated farming, raising livestock for power and income. Their livelihoods center on small-scale crop production, particularly maize, cowpea, and sorghum, along with fishing and foraging. A notable cultural practice is leaving weeds in fields to mulch the soil, which conserves moisture and enhances soil fertility through decomposition (Mengiste et al., 2025).

2.2. Research Design

This study employed a cross-sectional survey design, integrating both quantitative and qualitative methods to ensure comprehensive data collection. The qualitative component included key informant interviews, focus group discussions, and personal observations, while the quantitative component focused on household-level surveys. As emphasized by Fan & Yan (2020), the use of multiple methods and the triangulation of qualitative and quantitative approaches enhance the validity of findings by providing both complementary insights and convergence of evidence. In this study, the quantitative data were used to assess the selection of participating households, farmers' use of irrigation programs, income status, and the overall impacts of small-scale irrigation on household livelihoods. Meanwhile, the qualitative data provided deeper insights into the opportunities and challenges faced by smallholder farmers, thereby complementing the quantitative analysis.

2.3. Determination of Sample Size and Sampling Techniques

This study employed a cross-sectional research design and a two-stage stratified random sampling approach to select sample households. In the first stage, Itang Special District was purposively selected from the 13 districts in the Gambella region due to its irrigation potential. In the second stage, household heads in the selected district were stratified into irrigation users and non-users, based on consultations with agricultural experts and official records from the district agricultural office. Household lists were obtained from the district offices of finance and economic development and irrigation development (June 2024 report). To ensure comparability, non-users were selected from the *Kebele* where irrigation users were also located. Finally, respondents from each group were selected using simple random sampling, based on probability proportional to size, yielding a total of 294 rural household heads (192 irrigation users and 102 non-users). The sample size was determined using the simplified (Yamane, 1967) formula, which considers the total number of households (N), an acceptable margin of error (e), and the desired confidence level (z). At a 95% confidence level and 5% margin of error, the appropriate sample size was calculated as follows:

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

Where n is the sample size, N is the total household heads, and e is the level of precision (5 %).

Therefore, to determine the size of the sample household heads of each (n), the researcher is applying.

$$n_{k_i} = \frac{N}{\sum N} * \quad (2)$$

Where, the number of necessary samples of each group (user and non-user), N is the total households of each group, S is the total sample households to be treated (294), ΣN= Total households of the two groups (user plus non-user) =1104.

Table 1: Proportion of sample respondents of the study area

Sample Keble	Total HHHs category	Irrigation users*	Non users
Achewa	600	105	55
Itang-kir	504	87	47
Total	1104	192	102

HHHs=household heads, IUG=irrigation user group, NIUG=non-irrigation user group, *Source: Office report in June 2025

2.4 Data Collection Methods

The study drew on both primary and secondary sources of data. Primary data were collected through semi-structured questionnaires, focus group discussions (FGDs), and key informant interviews. In each selected Kebele, an FGD with eight to ten participants, men and women alike, was held to capture nuanced perspectives on the factors shaping farmers' adoption of small-scale irrigation practices. The semi-structured questionnaires explored farmers' perspectives on small-scale irrigation, alongside the socio-economic and institutional factors shaping their adaptation decisions. To complement and triangulate these primary findings, secondary data were obtained from the Itang Special District Office of Agriculture and Natural Resources, as well as from published journals and other relevant literature.

2.6. Binary Logistic Regression Model Specification

A binary logistic regression model was employed to identify the factors influencing the adoption of irrigation farming in the study area. This approach estimates the probability that a household either participates in irrigation farming (coded as 1, with probability P) or does not participate (coded as 0, with probability 1 – P). As highlighted by Dessie et al. (2019), the dependent variable in logistic regression is inherently binary, while the relationship between the dependent and independent variables is modeled through a logit transformation of P rather than a linear form. One of the key strengths of binary logistic regression, as emphasized by Dessie et al. (2019), is its ability to incorporate diverse explanatory variables, including continuous, discrete, and categorical factors. Following (Gujarati & Bernier, 2004), the general logistic regression model applied to assess household perceptions and determinants of irrigation adoption is specified as follows.

The probability that a technique is perceived can be specified as:

Pi=F (α + β xi)=1/1+ e – (α + β xi) (3)

Where Pi is the probability that the farmer's use of irrigation farming is given by xi, where x is a vector of explanatory variables and e is the natural logarithm.

Equation (1) can be rewritten as:

Pi=(1+ e – (α + β xi)) =1 (4)

Pi is between 0 and 1, where α + βxi=log (P1/1-Pi) and P1/1-Pi is the likelihood ratio, whose log gives the odds that a farm household's use of irrigation farming, whereas α is the constant of the equation β, is the intercept term. The regression can be expressed as:

Log (P1/1-Pi)=α + β0+ β1*X1 +… + B n* X n (5)

Where i denotes the ith farm household, (1……111); Pi is the probability of farm households using irrigation farming, and (1- Pi) is the probability of farm households not using it. While β0 is the intercept term, and β1, β2, β3...β n are the coefficients associated with each explanatory variable X1, X2, X3…X n, the estimation form of the logistic transformation of the probability of farmers' use of irrigation farming in the study areas.

During the data analysis, model fitness tests and assessments were used to ensure that the data were compatible with the chosen model. The classification tables (Fagerland & Hosmer, 2012) goodness-of-fit statistic and co-linearity and multi-collinearity statistics (through correlation matrices and Variance Inflation Factors/VIF) were employed to assess the model's fit to the data.

2.7. Statistical Data Analysis

A binary logistic regression model was employed to identify the key factors influencing households' adoption of irrigation farming in the study area. The model analyzed the relationship between the dependent variable (use of irrigation farming) and thirteen explanatory variables (Table 2), enabling the estimation of how each independent variable was associated with the likelihood of irrigation use. To provide a comprehensive understanding of respondents' characteristics, descriptive statistics such as percentages, means, and standard deviations were used. Inferential statistics, including t-tests for continuous variables and chi-square tests for categorical variables, were applied to test group differences. In addition, qualitative data from focus group discussions and interviews were analyzed thematically to enrich and contextualize the quantitative findings.

To ensure robustness, diagnostic tests for multicollinearity were conducted. All quantitative analyses were carried out using STATA version 17.

2.8. Definition of Variables and Working Hypotheses

Several factors are expected to shape households' decisions to participate in small-scale irrigation and determine the income they derive from it in the study area. To evaluate these factors, statistical tests were applied to compare users and non-users of irrigation. Specifically, t-tests were employed to examine differences in the mean values of continuous variables, while chi-square (χ^2) tests were used to assess the significance of categorical (dummy) explanatory variables.

After establishing the appropriate analytical approaches, the next step was to identify the potential explanatory variables, clearly define their measurements, and assign symbols for their representation. This section presents the key variables hypothesized to influence households' engagement in small-scale irrigation and the effects on their income levels.

The dependent variable: In this study is households' use of small-scale irrigation farming, with dummy values of 1 for households participating in irrigation farming and 0 for those not using irrigation in the study area.

The explanatory variables: In this study, both continuous and discrete (dummy) variables were expected to influence the dependent variable (use of irrigation farming). The variables included socio-demographic, economic, and institutional factors such as the age of the household head, sex of the household head, marital status, irrigation farming experience (years), household income level (measured in Ethiopian Birr), training participation in irrigation farming, education level, total landholding size (hectares), access to agricultural inputs (fertilizers and water pumps), access to credit, family size, tropical livestock units (TLU), and types of cultivated crops. Each variable was defined by its category, measurement unit, and hypothesized relationship with the dependent variable, as summarized in Table 2.

2.9. Conceptual framework of the study

Figure 2: The adoption of household irrigation practices is shaped by a combination of demographic, socio-economic, and institutional factors. Demographic characteristics, such as the sex and age of the household head, may either constrain or facilitate adoption by influencing decision-making and labor availability. Socio-economic factors—including education, family size, income, and livestock ownership determine households' capacity to invest in and sustain irrigation activities. Institutional elements, such as access to credit, training, extension services, and agricultural inputs, play a crucial role by reducing financial constraints and providing technical support. Importantly, these factors do not act in isolation but interact with one another, emphasizing that irrigation adoption is the outcome of a dynamic interplay between

household attributes, resource endowments, and institutional support systems.

Table 2: The descriptions of independent variables for model estimation

Variables	Description of variables	Expected sign
Sex of the household heads	1= Male HHHs; 0= Females	+
Marital status	1= Married, 2=divorced, 3= widowed	
Educational status of household heads	Cannot read and write=1, read and write =2, primary=3, secondary 4	+
Age of the household heads	Age of HHHs in years	-/+
Family size of the farmers	Family size of farm HHHs in number	-/+
Level income	income level of household heads	+
Experience in irrigation	Farmers experience irrigation=1, if not=0	
Inputs (fertilizers, pumps)	Farmers use fertilizer in put=1, if not=0	+
Access to credit	Farmers accessed to credit =1, if not= 0	-
Access to training	Farmers accessed to training =1, if not=0	+
total land size (hectares		
Tropical livestock units (TLU)	Tropical livestock unit of HHH in number	+
Cultivated crop types	HHHs cultivate cereal crops=1, if not=0	-/+

HHHs; household heads, TLU; tropical livestock unit, BIRR; benefits of irrigation

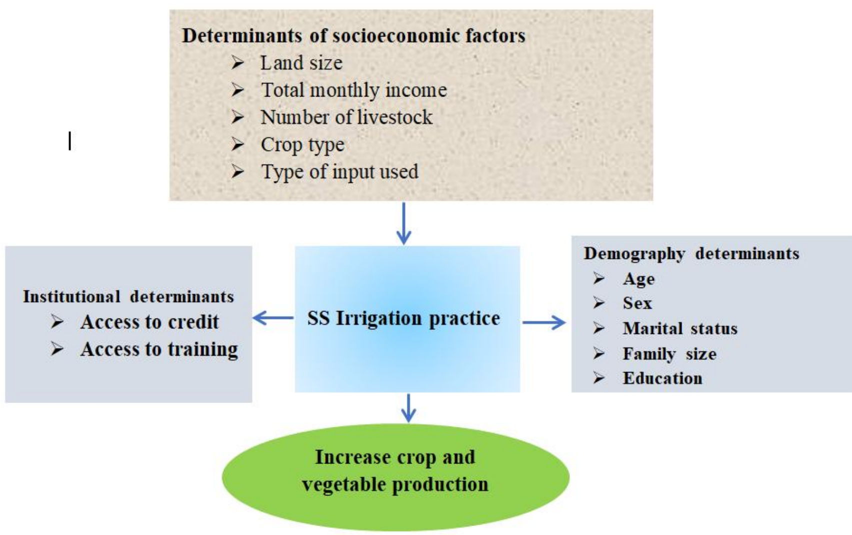

Figure 2: Conceptual Framework of the Study

3. Results and Discussions

3.1. Descriptive statistics of the f sample respondents

The descriptive statistics were employed to examine the distribution of independent variables between irrigation users and non-users. The socio-economic and institutional characteristics considered included sex, marital status, educational level, and access to training, access to credit, irrigation experience, input use, cultivated crop types, age, family size, and livestock holding. Out of the total 294 sampled households, 192 (65.3%) were irrigation users, while 102 (34.7%) were non-users.

3.1.1. Socio-Economic and Institutional Characteristics of Sample Households

The results indicated that approximately 29.23% of small-scale irrigation adopters, compared to only 10.75% of non-adopters, perceived an increase in temperature due to climate change. A Pearson chi-square test confirmed that this difference was statistically significant at the 1% level. Overall, about 65.3% of respondents were irrigation users, while 34.7% were non-users. The chi-square analysis further demonstrated a significant difference between users and non-users at the 1% significance level, suggesting that participation in irrigation is not randomly distributed across households but is shaped by underlying socio-economic and institutional factors.

The survey results reveal a statistically significant gender disparity between irrigation users and non-users (χ^2=12.18, df=293). Among irrigation users, 177 (92.1%) are male-headed households and only 15 (7.9%) are female-headed, whereas among non-users, 84 (82.3%) are male-headed and 18 (17.7%) are female-headed. Overall, 261 (88.8%) of respondents are male and 33 (11.2%) are female, highlighting that irrigation adoption in the study area is predominantly associated with male-headed households.

The distribution of household income levels revealed a clear difference between irrigation users and non-users. Out of the total 294 households, 192 (65.3%) were irrigation users, while 102 (34.7%) were non-users. This result also suggests that a larger share of households with relatively better income levels were engaged in irrigation activities compared to those that did not practice irrigation. The χ^2=3.22, $p < .000$) further indicates that the association between household income level and irrigation use was statistically significant. This implies that household income status is an important factor influencing the likelihood of adopting irrigation practices in the study area. Regarding marital status, nearly 181 (94.3%) of irrigation users are married, while 4 (2%) are divorced and 7 (3.7%) are widowed. In the non-user category, about 84 (82.3%) are married, and 10 (9.8%) are divorced (Table 3). In total, 265 (90.1%) of the sampled respondents are married, while the remainder are either divorced or widowed. The statistical analysis indicates a significant difference in marital status between irrigation users and non-user households, with a Chi-square value of (χ^2=19.44, DF=293, $p < 0.01$) in the study area.

Educational attainment is another critical factor; approximately 125 (65.1%) of irrigation users cannot read or write, while nearly 85 (83.3%) of non-users are similarly illiterate. This data suggests that a total of 210 (71.4%) of all respondents lack basic literacy skills (Table 3). Conversely, 55 (28.6%) of users have attended formal education, and 10 (5.2%) have completed primary education (grades 1-8) (Table 3). Among non-users, around 13 (12.7%) have attended formal education, and 2 (2.2%) have completed primary education (Table 3). Notably, only 2 (1.1%) of users and 1 (1.8%) of non-users have attended secondary school. Overall, 210 (71.4%) of the sample respondents are uneducated, while 83 (28.6%) have received either informal or formal education. The Chi-square value (χ^2=18.65, DF=293, $p < 0.01$) confirms a significant educational disparity between irrigation users and non-users in the study area.

Training plays a crucial role in irrigation use. Among respondents, 145 (75.5%) users and 25 (24.5%) non-users received irrigation-related training. Overall, 170 (57.8%) participants had training, while 124 (42.2%) had none. More non-users lacked access to training compared to users, with a significant variation (χ^2=22.71, DF=293, $p < 0.01$). Similarly, 151 (82.3%) users obtained credit for irrigation, while 25 (24.5%) non-users accessed credit for other purposes. In total, 164 (55.7%) respondents received credit, showing a significant difference between groups. About 178 (92.7%) users had irrigation experience, while 10 (9.8%) non-users understood irrigation without applying it. This difference was significant (χ^2=23.83, DF=293, $p < 0.01$) (Table 3). Fertilizer use was also higher among users (165, 85.9%) than non-users (7, 6.8%), with a significant difference (χ^2=22.41, DF=293, $p < 0.01$) (Table 3). Perception of irrigation benefits was reported by 139 (72.3%) users and 41 (40.2%) non-users, totaling 180 (61.2%) respondents, with a significant difference (χ^2=13.427, DF=293, $p < 0.05$) (Table 3). Regarding crop types, 101 (52.6%) users and 78 (74.5%) non-users cultivated irrigated crops. Overall, 177 (60.2%) respondents used some irrigated crops, with a significant difference (χ^2=11.213, DF=293, $p < 0.05$) (Table 3). The mean age of users was 46.2 years (SD=±7.013) and non-users 48.45 years (SD=±9.439), with an overall mean of 47.22 years (SD=±5.66), showing a significant difference (t=-2.33, $p < 0.05$) (Table 3). Mean family size was larger among users (6.81, SD=±1.540) than non-users (5.73, SD=±1.653), with a significant difference

($t=-8.94$, $p < 0.01$) (Table 3). Landholding size averaged 3.2 ha for users and 2.5 ha for non-users, with a significant difference ($t=-11.87$, $p < 0.01$). Similarly, mean TLU was higher among users (3.67, SD=±1.123) than non-users (2.97, SD=±1.872), with a significant difference ($t=-2.401$, $p < 0.05$) (Table 3).

Table 3: Descriptive statistics of sample respondents

Categorical variables	Irrigation users (n=192)	Non-users (n=102)	Combined (n=294)	χ^2
Sex of HHH (% male)	177 (92.1%)	84 (82.3%)	261 (88.8%)	12.18**
Fimale	15 (7.9%)	18 (17.7%)	33 (11.2%)	
Marital status of HHH				
Married	181(94.3 %)	84 (82.3 %)	265 (90.1%)	19.44***
Divorced	4 (2%)	10 (9.8 %)	14 (4.7 %)	
Widowed	7 (3.7%)	8 (7.9%)	15 (5.2 %)	
Educational level				
Cannot read or write	125 (65.1 %)	85 (83.3 %)	210 (71.4 %)	18.65***
Can read and write	55(28.6 %)	13 (12.7 %)	68 (23.1%)	
Primary grade (1-8)	10(5 .2 %)	2 (2.2 %)	12 (4.1 %)	
Secondary grad (9-12)	2 (1.1 %)	1(1.8 %)	3 (1.4%)	
Access to training	145 (75.5%)	25 (24.5%)	170 (57.8 %)	22.71***
Access to credit	151(82.3%)	13 (31.9%)	164 (55.7)	17.87***
Experience in irrigation	178(92.7%)	10(9.8%)	188(63.9%)	23.83***
Inputs	165 (85.9%)	7(6.8%)	172(58.5%)	22.41***
Cultivated crop types	101 (52.6%)	76 (74.5%)	177 (60.2%)	11.213**
Continuous variables				t-value
Age (mean ± SD)	46.21 ±7.013	48.451±1.439	47.22± 5.66	-2.33**
Income level	192(65.3)	102(34.7)	294 (100%)	3.22***
Family size (mean ± SD)	6.81±1.540	5.73 ± 1.6533	5.32 ± 1.876	-8.94***
Land size	1.9(65.31)	1.179(34.69)	294 (100%)	-4.58**
TLU (mean ± SD)	3.67±1.123	2.97±1.872	3.101±1.769	-2.401**

***=Significant at 1%, **=significant at 5%, SD=Standard deviation, DF=Degree of freedom, HHH=household heads, Source: Developed from the survey result, 2025

3.2. Determinants of Farmers' Use of Small-Scale Irrigation Practices: Binary Logistic Regression Model

This section examines the determinants of farmers' use of small-scale irrigation in the Achewa area, Gambella, Southwestern Ethiopia. The binary logistic regression model was estimated using maximum likelihood methods (Table 4). The likelihood ratio (LR) test χ^2 (13) =353.22, p=0.000, confirmed that the model fits the data at the 1% significance level. The likelihood ratio=-13.1745 and Pseudo R^2=0.9306 also indicate good model fit, supporting the null hypothesis that independent variables adequately explain the disturbance terms (Fagerland & Hosmer, 2012). Diagnostic tests showed tolerance values close to 1 and VIF values below 10 for all independent variables, suggesting no multicollinearity (Uyanık & Güler, 2013). Out of 12 hypothesized predictors, all significantly influenced households' irrigation use (Table 4). With several variables

showing significant coefficients ($p<0.05$), the model demonstrates strong explanatory power. Sex of household head was a key determinant at the 1% significance level (Table 4). Male-headed households were more likely to adopt irrigation than female-headed households. The negative coefficient for "sex" indicates female household heads are less likely to use irrigation, as they are often engaged in household tasks such as childcare and cooking. Key informants and FGDs noted that female-headed households received less training from Development Agents, limiting their participation. These findings align with Abdissa et al. (2017), who reported significant differences between irrigation users and non-users by sex at the 1% level, with male-headed households more likely to adopt irrigation. Similarly, social norms restricting women's decision-making have influenced irrigation adoption in South Asia

(Ullah et al., 2023). In contrast, some studies (Asfaw Eshetu & Mekonen, 2024; Mare, 2017) found male- and female-headed households equally likely to participate in irrigation in the Geray Irrigation Scheme, Northwest Ethiopia.

Age of household heads: Regression results show a significant negative relationship between age and irrigation use (Coef. = –0.557, $p < 0.05$), indicating older farmers are less likely to adopt irrigation (Table 4). Younger households appear more open to small-scale irrigation, consistent with findings that older farmers are risk-averse and less inclined to adopt innovations (Gebrehiwot & Van Der Veen, 2013; Teha & Jianjun, 2021; Zemarku et al., 2022). Similarly, Gemeda et al. (2022) reported that younger farmers invest more in irrigation when supported by market access and training.

Marital status of heads: Most respondents are married: 181 (94.3%) users and 84 (82.3%) non-users, representing 90.1% overall. Divorced (2% users; 9.8% non-users) and widowed (3.7% users; 7.9% non-users) households form 5.2% of the sample. The Chi-square test (χ^2=19.44, $p < 0.01$) confirms a significant association between marital status and irrigation adoption, with married households more likely to adopt irrigation due to combined labor and stable resources (Asfaw Eshetu & Mekonen, 2024; Kateb et al., 2025). Regression results also show a significant negative effect at the 5% level (Table 4). Similar findings were reported by Nakawuka et al. (2018), though Esponda et al. (2021) highlighted that single-headed households, especially women-led, can achieve comparable adoption rates when given education and financial access.

Education level: Education positively and significantly influences irrigation adoption (Coef. =2.182, $p < 0.001$; Table 4). Educated farmers are better able to understand innovations, supported by evidence that literacy enhances responsiveness to extension and modern technologies (Asfaw Eshetu & Mekonen, 2024; Mengistie & Kidane, 2016; Kifle et al., 2016). However, contextual factors like local practices and resource access may override education (Álvarez et al., 2021; Godwin & Johnson, 2025).

Family size: Family size is positively associated with irrigation (Coef. =1.291, $p < 0.001$; Table 4). Larger households supply labor for irrigation, supporting earlier findings (Aryal et al., 2018; Abegunde et al., 2020; Alemu et al., 2022; Asfaw et al., 2019). FGDs confirmed that bigger families mobilize members into productive work, whereas smaller families face labor shortages.

Access to training: About 75.5% of users and 24.5% of non-users received training, with overall access at 57.8%. The Chi-square test (χ^2=22.71, $p < 0.01$) shows a strong link with irrigation (Table 4). Training improves awareness and water-use efficiency (Abegunde et al., 2020; Aryal et al., 2018; Abdissa et al., 2017). However, constraints like finance may limit its impact (Ndlovu & Chikobvu, 2022), underscoring the need for integrated support.

Access to credit: Credit access was reported by 82.3% of users versus 31.9% of non-users, with an overall rate of 55.7%. The association is statistically significant (χ^2=17.87, $p < 0.01$; Table 4). Credit enables investment in irrigation, aligning with findings from Awunyo & Ziba (2017) and Fissahaye et al. (2023). FGDs emphasized that expanding credit services would strengthen irrigation adoption, though financial management training is also necessary.

Livestock holdings (TLU): Users held 3.67 ± 1.12 TLU, compared to 2.97 ± 1.87 for non-users (mean=3.10 ± 1.77), with a significant effect (Coef. =1.602, $p < 0.05$; Table 4). Livestock holdings reflect wealth and provide cash for inputs, facilitating irrigation adoption (Wolka et al., 2023; Abdissa et al., 2017; Zegeye et al., 2001).

Experience with irrigation: Experience is positively associated with adoption at $p < 0.01$ (Table 4). Prior experience builds confidence and competence (Zhai et al., 2015), though excessive reliance on traditional methods can reduce openness to innovations (Fadl et al., 2024).

Income level: Income has a significant positive influence ($p < 0.01$; Table 4). Higher-income households can afford irrigation technologies and inputs, while low-income households face financial barriers. This confirms that financial capacity is critical for adoption (Haile et al., 2024).

Inputs (fertilizers, pumps): Fertilizers and pumps are significantly linked with irrigation adoption at 5% (Table 4). Fertilizers and irrigation act synergistically, while pumps are vital for efficient delivery. Input availability and affordability strongly affect adoption (Zhai et al., 2015).

Cultivated crop types: Crop choice significantly affects irrigation decisions at 5% (Table 4). High-water-demand and high-value crops (e.g., rice, vegetables, fruits) encourage irrigation adoption. USDA Economic Research Service (2025) notes that crop water needs and profitability shape irrigation allocations.

Table 4: Determinants of households' use of small irrigation practices

Determinant variables	Coef.	St. Err	Z	P>|z|	95% Conf. Int.	
Sex HHH	-12.85***	3.42	3.75	.000	-13.121	4.254
Age of HHH	-0.55**	.22	2.50	.042	-.781	-.004
Marital Status	-5.15**	2.10	2.45	.034	-6.470	-1.302
Education Level	2.18***	.60	3.63	.001	1.051	4.309
Family size	1.29***	.34	3.79	.000	-1.200	3.070
Access to training	4.64***	1.39	3.33	.001	3.215	5.288
Access to Credit	2.98***	.98	3.04	.006	-.008	3.002
Livestock holding	1.60**	.77	2.07	.025	1.981	2.008
Irrigation Experience	.974***	.24	4.05	.000	-.213	1.220
Level of income	1.60***	.17	3.22	.000	3.514	6.991
Inputs (fertilizers)	1.66**	.77	2.15	.044	-1.370	2.331
Cultivated crop	.865**	.35	2.47	.037	-1.001	.967
Land size	.4823	1.056	0.46	0.648	-2.55	0.04
Con	47.066**	21.324	2.20	.044	7.100	91.032
No. Obs	294					
likelihood ratio	353.22					
Prob > chi2	0.00					
Log likelihood	-13.174					
Pseudo R2	.9306					

***=Significant at 1%, **=significant at 5%, Source: Developed from survey results, 2025

In the focus group discussions, participants emphasized the crucial role of gender in irrigation practices, noting that male-headed households tend to have better access to resources and training, while female-headed households face societal constraints that limit their participation. They also highlighted the influence of age, with younger farmers being more open to adopting new irrigation technologies compared to older, more risk-averse farmers. Additionally, participants pointed out that larger family sizes contribute to greater labor availability for irrigation activities, making it easier to manage labour-intensive tasks.

Key informants provided insights into the significance of marital status and education in irrigation adoption. They noted that married individuals often benefit from collaborative decision-making and financial stability, which can enhance investment in irrigation systems. Education was identified as a critical determinant, as higher educational attainment correlates with increased adoption of irrigation practices. Informants also discussed the importance of access to training and credit, emphasizing that financial resources enable investment in irrigation technologies, while experience with irrigation significantly influences effective implementation. Perceptions of irrigation were highlighted as well, with positive experiences encouraging adoption, while concerns about costs and management challenges could deter farmers.

3.3. Limitations

The findings may not be generalizable beyond the specific geographic area of Achewa, limiting their broader applicability. The cross-sectional design of the study restricts causal inferences regarding the relationships between variables, and the reliance on self-reported data may introduce biases. Additionally, while several factors are analysed, other influences on irrigation adoption, such as climate change impacts or market access, were not considered, and the study does not account for temporal changes in agricultural practices or external influences that could affect irrigation trends.

3.4. Future studies

Future studies should consider conducting longitudinal research to track changes in irrigation adoption over time, allowing for a better understanding of trends and causal relationships. Gender-focused research is essential to explore barriers and opportunities for female farmers, while expanding the geographic scope to include diverse regions can enhance the generalizability of findings. Investigating the impact of climate change on irrigation practices and assessing the role of technology adoption will provide valuable insights. Additionally, examining the effectiveness of financial products tailored for farmers and exploring community-based training initiatives can inform targeted interventions. Incorporating cultural issue factors will further enrich the understanding of irrigation use dynamics.

4. Conclusions

The research findings indicate a significant gender disparity in irrigation use, with 92.1% of irrigation users being male and only 7.9% female, highlighting the need for initiatives that promote women's involvement in agricultural practices. Marital status also plays a crucial role, as married household heads are more likely to engage in irrigation, suggesting that stable family structures may enhance agricultural investments. Furthermore, the data reveal a strong correlation between education levels and irrigation adoption; higher educational attainment significantly increases the likelihood of utilizing irrigation technologies, underscoring the importance of education in fostering agricultural innovation. Access to training and credit emerges as a vital factor, with a majority of irrigation users benefiting from these supports, which can facilitate the adoption of effective agricultural practices. Additionally, households with previous irrigation experience and positive attitudes toward its benefits are more inclined to use and successfully implement irrigation systems. Key determinants of irrigation use include the sex and age of household heads, family size, access to training and credit, experience with irrigation, and perceptions of its benefits, all of which collectively influence the likelihood of adopting irrigation practices.

In terms of policy implications, there is a pressing need for gender inclusivity initiatives that encourage women's participation in irrigation through targeted training and resource allocation. Investments in agricultural education and literacy programs can enhance farmers' understanding of irrigation technologies, thereby increasing adoption rates. Governments and NGOs should also facilitate accessible training programs, particularly for non-users, to build capacity in irrigation practices. Moreover, introducing tailored credit products for agriculture can help alleviate financial barriers, enabling more farmers to invest in irrigation systems. Awareness campaigns that improve farmers' perceptions of the benefits of irrigation and address concerns about costs and management challenges can further enhance adoption rates.

Author Contributions:

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Conflicts of interest

The authors of this article declared no conflict of interest regarding the authorship or publication of this article.

Data availability statement:

All data generated or analyzed during this study are included in this published article.

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