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Determinants of small-scale irrigation adoption in drought-prone areas of northcentral Ethiopia in the context of climate change

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Introduction: One feasible way to prepare for the adverse effects of climate change in rainfed-dependent livelihood zones is through irrigation. This study examines small-scale irrigation practices and their determinants.

Methods: Using structured survey questionnaires, interviews, and field observations, we used a cross-sectional survey design to collect data from 380 randomly selected households. The data analysis involved percentages, problem confrontation index, Chi-square test, independent samples t-test, and binary logistic regression model.

Results: The findings revealed that river/stream diversion (40%), using nearby springs (19%), and hand-dug walls (18%) were the predominant types of irrigation. At the same time, water scarcity (PCI = 743), land shortage (PCI = 345), and labor (PCI = 212) were the main impediments to irrigation practices. The binary logistic regression model revealed educational status (OR = 1.239, $p < 0.05$), headship type (OR = 0.246, $p < 0.05$), age (OR = 0.943, $p < 0.05$), relative agroecological location (OR = 7.605; 13.929, $p < 0.05$), family size (OR = 1.936, $p < 0.05$), land size (OR = 8.609, $p < 0.05$), responsibility (OR = 2.069, $p < 0.05$), and crop failure (OR = 0.389, $p < 0.05$) as factors affecting the adoption of small-scale irrigation.

Discussion: We recommend offering financial assistance to farmers with limited resources to acquire and install labor- and water-saving irrigation systems. Training and extension services on operating and maintaining small-scale irrigation technologies should be provided. Timely information sharing is also necessary to increase the use of irrigation on a small scale as a feasible adaptation to climate change.

KEYWORDS

small-scale irrigation, climate change adaptation, northcentral Ethiopia, binary logistic regression model, rainfed agriculture

1 Introduction

Climate change is one of our day's most significant development concerns, particularly for smallholder farmers in developing nations primarily relying on natural systems and those lacking irrigation access (IPCC, 2022). Climate change significantly threatens global crop production

(Myers et al., 2014). Changing precipitation patterns, more frequent extreme weather events, and rising temperatures have already reduced global yields of major crops like wheat, corn, and soybean by 3–6% since the 1960s (Iizumi et al., 2022). Without robust mitigation and adaptation efforts, climate change could decrease global crop yields by up to 30% by the end of the century. In Ethiopia, where about 90% of food production comes from rain-fed smallholder agriculture, the impacts of climate change on crop production are profound and make the country highly vulnerable to adverse effects of climate change (Alemu and Dessale, 2022). A study in Ethiopia by Solomon et al. (2021), using a general equilibrium model estimated that crop production will be adversely impacted by a changing climate for the coming four decades particularly the production of *teff*, maize and sorghum will decline by 25.4, 21.8 and 25.2 percent, respectively by 2050 compared to the base period.

Irrigation is a feasible adaptation strategy to mitigate the risks of potential reductions and yield unpredictability brought on by climate change. Those with better access to irrigation will be less vulnerable than those relying solely on rain-fed agriculture (Finger et al., 2011). Thus, developing affordable but water-efficient irrigation systems is one of the most essential and practical approaches to tackling the problems of climate change and low agricultural productivity in Sub-Saharan Africa (Ngango and Hong, 2021; Teha and Jianjun, 2021). According to Alemu and Dessale (2022) and Mume et al. (2023), small-scale irrigation (SSI) is becoming the primary strategy for strengthening and building resilient rural livelihoods in Ethiopia, especially given the nation's increasingly erratic and unpredictable rainfall patterns. Empirical research demonstrated that efficient irrigation practices could potentially increase employment, providing farmers with more work for more extended periods throughout the year, thus contributing to food security; well-managed irrigation development reduces the adverse effects of high climate variability on agricultural productivity, enhances smallholder livelihood and income, and extends agricultural seasons to counteract population pressure on land and the consequent degradation of soil and land (Awulachew, 2010; Awulachew and Ayana, 2011). According to Tesfaw (2018), irrigation is essential for improving the food security status of rural communities since it lowers the chance of crop failure and increases potential yields in areas susceptible to drought.

Ethiopian agriculture is primarily rain-fed (about 90% of the food production comes from rainfed smallholder agriculture) with limited use of its irrigation potential. Hence, it is susceptible to the adverse effects of rainfall variability (Birhanu et al., 2019). Expanding irrigation farming to support rain-fed agriculture is a crucial tactic. Furthermore, it increases smallholder farmers' resilience to climate variability's impacts, reduces farmers' vulnerability to rainfall variability, enhances their food security and stimulates agricultural intensification (Awulachew and Ayana, 2011). Irrigation practices generate new livelihood opportunities, boost production and productivity, and attain food and nutritional security (MoA, 2011).

According to Zemarku et al. (2022) and Ngango and Hong (2021), SSI also improves the rural community's general standard of living by boosting income, securing food, meeting societal responsibilities, and reducing poverty. A key component of enhancing the food security of rural households is irrigation technology, which also helps farmers grow various high-value crops and enhances their nutritional standing (Hagos et al., 2009). Amede (2011) has emphasized that irrigated agriculture is a critical intervention in helping developing nations like Ethiopia accomplish their food security goals and eliminate poverty. According to Tesfaye et al. (2008), Amede (2011), Finger et al. (2011), and Birhanu et al. (2019), there are several reasons why irrigation agriculture is vital in drought-stricken Sub-Saharan Africa. These reasons include lowering farmers' susceptibility to fluctuations in rainfall, raising agricultural productivity per unit of land, which in turn prevents farming from spreading to less productive and fragile ecosystems, enabling communities to create high-value businesses on homesteads, bolstering group action for more comprehensive land and water management, and managing upper watersheds of command areas, among other things. According to Awulachew (2010), the development of irrigation technology may enable higher land and labor productivity, minimize resource degradation, increase a nation's export base, enhance household nutrition, create more job opportunities, and encourage rural entrepreneurship. Based on a study carried out in Ethiopia's Tigray region by Getacher et al. (2013), using the Hickman two-stage model and ordinary least square, SSI significantly and favourably improves the income status of rural farm households. Adopting irrigation technology is necessary for raising agricultural yield and rural communities' food security, as Hagos et al. (2009) mentioned. Above and beyond, it enables smallholder farmers to produce high-value and diversified crops, significantly improving their nutritional and welfare status. A study by Belete and Melak (2018) in the Amhara regional state (Ethiopia) on the impacts of irrigation adoption on the nutritional well-being of children found that children from families of SSI technology adaptors had better nutritional status than their counterparts. Using the propensity score matching approach, the study found that non-adopting households had a higher proportion of underweight individuals than their adopting counterparts. Jambo et al. (2021) revealed that farmers who participated in SSI in Ethiopia were better at their daily calorie intake than their counterparts, and irrigation positively enhanced crop productivity, consumption, and revenue. A study conducted in Ethiopia's Oromia regional state (Teha and Jainjun, 2021) and Filtino and Godino (Tesfaye et al., 2008) affirmed a significant effect of SSI on households' livelihood in improving their income and expenditure, together with an increase in expenditure on agricultural inputs. Similarly, a study by Solomon and Ketema (2015) in Fogera Woreda (North-wester Ethiopia) found a statistically significant difference in annual *per capita* consumption expenditure between irrigation users and non-users, favoring the former. A study in agropastoral community in South Omo of Ethiopia by Asmera and Yidnekachew (2021) uncovered that the income status of irrigation users was found to be much better than non-users since participation in irrigation enabled them to diversify their products and creates opportunity to harvest more than once a year.

According to Mekonen and Berlie (2021), Ethiopia has abundant surface and groundwater resources, which makes the country potentially rich for irrigation agriculture, but the country's current irrigation development is insignificant. In Ethiopia, only a small proportion of land is irrigated, and its performance is inadequate (Awulachew, 2010; Awulachew and Ayana, 2011; Mekonen and Berlie, 2021). The Central Statistical Agency (CSA, 2021) estimated that the irrigated land in Ethiopia is around 5% and contributes only 3 percent of total food crop production, much lower than the African average. This implies that the land used under irrigation is almost negligible despite its vast potential. A recent meta-analysis study conducted by Girma (2022) in Ethiopia revealed that adopting irrigation technologies is very low (4.7%) compared with the country's massive potential.

Similarly, Shita et al. (2018) disclosed that the irrigation adoption rate in Amhara regional state was only 6.15%. Though South Wollo is among the most drought-prone areas in the Amhara regional state, and the adoption rate of modern irrigation is meager compared with its potential, in-depth analysis of the critical determinants impacting SSI adoption in the study area is limited. As a result, this study sheds light by investigating the status and quantifying the determinants of the adoption of irrigation in the face of climate change at the household level using the adoption of innovation theory. To better understand how farmers adjust irrigation strategies in the face of climate change, our research adds to the body of literature by taking a quantitative approach. People may adopt, not adapt, or adapt partially different agricultural technologies for various reasons. Leary and Kulkarni (2007) pointed out other possible reasons (socio-economic, biophysical, and institutional attributes) that conditioned people to adopt or not to adopt technologies (see Table 1 for a detailed explanation of hypothesized variables). We looked into the key factors influencing the adoption of SSI in the context of climate change using the innovation-diffusion model as a lens. The innovation-diffusion model, which is based on Rogers' (1962) research, argues that the main factor influencing an innovation's decision to be adopted is access to information about it (Wejnert, 2002). The model unanimously acknowledged communication's role in adopting new technologies; consequently, methods are streamlined through experiment stations, the media, extension, and local opinion leaders (Adesina and Zinnah, 1993).

Nevertheless, according to the adoption-perception model, a prospective adopter's perception depends on various factors, such as their educational background, experiences in life, and moral principles (Sarker et al., 2013). According to Sarker et al. (2013) and McNeely et al. (2014), the practicality and acceptability of adoption are impacted by the perception of risk and susceptibility to risk. According to the utility-maximizing economic constraints model, the adoption of new technologies is affected by production factors like labor, land, credit availability, and other necessary inputs (Makokha et al., 1999).

2 Materials and methods

2.1 Description of the study area

Borena district is situated in the northcentral part of Ethiopia. According to Abebe (2023) and Nurye et al. (2023), the district is located between 10°34′02″ and 10°53′16"N and 38°27′39″ to 38°54′20″E (Figure 1). Its estimated area is 937 km^2. The district is bordered by the Abay River on the west, which divides it from the East Gojjam Zone, Wegdie district on the south, Sayint district on the northeast, Mehal Sayint district on the north, Legambo district on the east, and Sayint district on the west (Abebe, 2023). The center of its administration is Mekane Selam town.

2.2 Biophysical situation of the study area

The district is defined by its varied topography, which ranges from 500 meters to 3,700 meters above sea level. Due to its diverse topography, the district is divided into four traditionally recognized agroclimatic zones: Kola (32%), Woinadega (47%), Dega (20%), and Wurch (1%; Shiferaw and Singh, 2011; Abebe, 2023). The area is distinguished by a summertime rainfall maximum from June to September and intermittent showers from March to May. Mean annual rainfall in the district ranges from 889 to 1,500 mm (Shiferaw and Singh, 2011; Nurye et al. 2023). The district's mean temperature varied between 14 and 19°C, while its annual maximum and minimum temperatures ranged from 13 to 31°C and −0.5 to 16°C, respectively. Shiferaw and Singh (2011) state that the district's upper northwest region has the lowest temperature and is primarily Wurch-type, while the southwest region has the highest temperature and is classified as Kolla climatic. There is minimal natural cover in the area due to heavy deforestation. Other native tree species are almost non-existent, except for a few scattered acacia trees, farmer-planted eucalyptus patches, and a few bushes and shrubs (USAID, 2009). Vertisols, rich in clay and have deep cracks when dry, make up most of the soil types in Borena. Even though these soils are suitable for farming, erosion is frequent (Shiferaw and Singh, 2011).

2.3 Socio-economic situation of the study area

The district's overall population was projected to be 187,915 people in 2017. There were 94,756 females and 93,159 males among them. The district's population density is 153.96 persons per km^2, greater than the South Wollo zone (143.58 persons per km^2). Borena's economy is mainly focused on agriculture, where the cultivation of crops and livestock rearing constitute the primary economic pillars of the local communities in the area (Asfaw, 2014; CSA, 2021). Cultivation of both long and short-cycle crops is entirely rainfed, except in a few select locations that use small-scale, traditional irrigation practices. Alongside growing crops, the communities have a higher livestock asset due to their significance for cash income, milk production, land plowing, and food (Mekonen and Berlie, 2021). Cattle, Sheep, goats, and equines are the primary livestock types raised in the area and contribute significantly to household earnings. However, various factors, including severe frost, hailstorms, limited input availability, soil erosion, water scarcity, and low and irregular rains with late-onset and early cessation, contribute to low agricultural productivity, resulting in chronic food insecurity in the area (USAID, 2009; Mekonen and Berlie, 2021). Borena's native vegetation is primarily composed of grasslands and woodlands. However, excessive grazing and deforestation have seriously degraded the vegetation

TABLE 1 Total household heads and sample size.

District	Location	Kebele	HHHs	Sample size	5% contingency	Total sample size
Borena	Upper-land	Hulagosh and Chefebelo	3,371	127	6	133
	Middle-land	Debrsenbo and Dibiechere	3,636	137	7	144
	Lower-land	Derami and Miskabie	2,813	106	5	111
		Total	9,820	370	18	388

Source: BWDoAO, 2021.

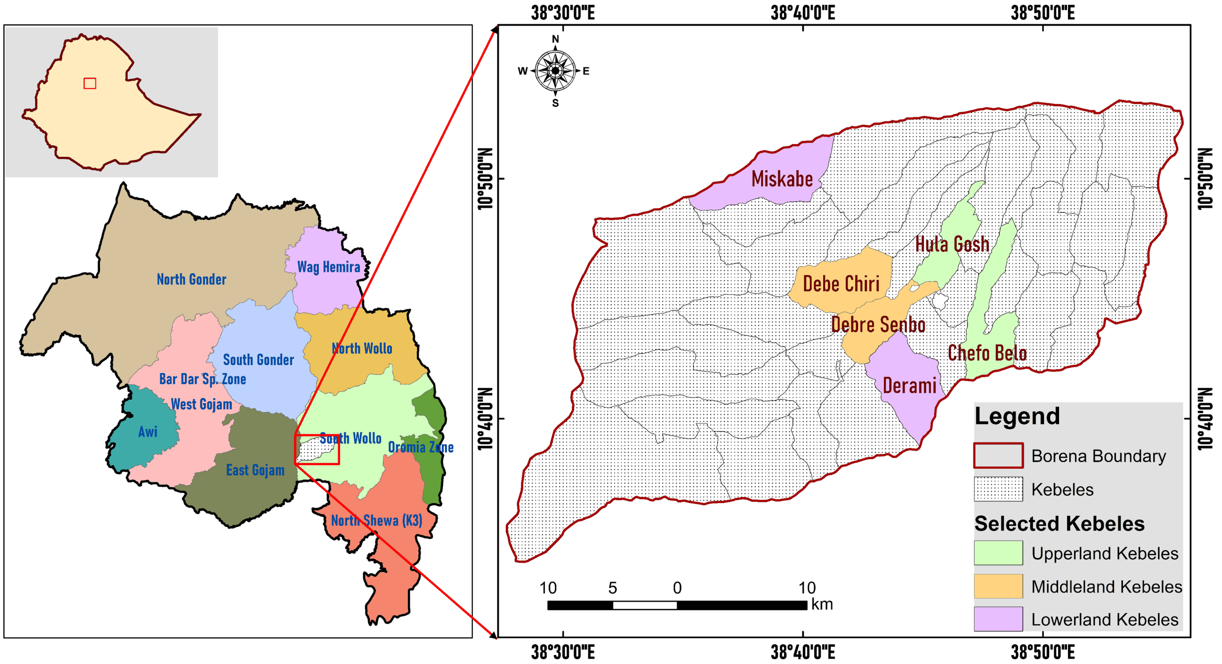

FIGURE 1
Relative location of the study area (Source: Wollo University GIS team, 2023).

cover. Several perineal rivers drain the district, and the Abbay River, which forms its western boundary, offers a sizable potential water supply for irrigation (Shiferaw and Singh, 2011; Asfaw, 2014).

2.4 Research design

2.4.1 Data: type, source, tools, and analysis techniques

We employed a cross-sectional survey design to estimate the determinants of smallholder farmers' participation in SSI practices in the context of climate change. We collect primary data using a survey questionnaire, actual field observation, and critical informant interview (KII) from February 2021 to May 2021. Data were collected mainly from household heads and concerned government bodies at different levels using pilot-tested structured survey questionnaires (Cronbach alpha value of 0.0.86) and checklists. Well-trained data enumerators collected survey data while the authors conducted field observation and KII. The data was analyzed using Chi-square, independent samples t-tests, mean, and percentage to examine mean differences and associations between SSI practitioners and their counterparts based on various attributes. We used a binary logistic regression model to find the key factors influencing participation in irrigation practices. The prominent problems faced were analyzed using the Problem Confrontation Index. Quantitative analysis was triangulated with outputs of KII and field observation. The multicollinearity problem among independent variables was checked before running the model using the Variance Inflation Factor (VIF) and contingency coefficient. The model's goodness was checked using Hosmer-Lemeshow and Omnibus tests. We employed statistical Package for Social Science (SPSS ver. 27) software for data analysis. The unit of analysis in identifying determinants of smallholders' engagement in SSI activities was done at the household level.

2.4.2 Target population and sampling technique

For the cross-sectional survey design, the target populations were smallholder farmers. Samples were using a proportionate stratified random sampling technique. Borena *woredas* was purposively selected considering its heterogeneity in agroecology and its vast potential for irrigable land but minimal actual practices. Six kebeles (two from each location, upper land, middle land, and lower land, which were classified based on their relative location, not necessarily based on their agroecological division) were randomly selected out of 12 potentially rich kebeles (out of 36 rural kebeles) for irrigation practices based on consultation with Borena woreda irrigation experts. Household heads from the chosen kebeles were selected using a systematic random sampling technique from a list derived from corresponding kebelle administrations. We included 5% as a contingency based on Israel (2012) for the non-response rate and to compensate absentees. Thus, 388 household heads were randomly and proportionately selected from the six kebelles (see Table 1).

Moreover, four individuals from *Woreda* agricultural offices and four individuals engaged in SSI were included purposively for KII based on their expertise in the field of study and engagement in irrigation economic activity. The sample size determination for the survey study was computed based on Kothari (2004):

$$
\begin{aligned}
n &= \frac{Z^2 * N * p * q}{e^2 (N-1) + Z^2 * p * q} = \\
n &= \frac{[3.8416 * 9820 * 0.5 * 0.5]}{[0.0025(9820-1)] + [3.8416 * 0.5 * 0.5]} \\
&= 370 + 5\% = 388
\end{aligned}
$$

Where N is the total target population, n is the desired sample size, Z is the standardized, average deviation set at 1.96 to 95% confidence level; p is the estimated proportion of an attribute that is present in the population (0.5); q is the estimated proportion of an attribute that is not present in the population (1-p; 0.5); e is the degree of accuracy required generally set at 0.05 (5% of acceptable sampling error).

2.4.3 Model specification

2.4.3.1 Binary logistic regression

We applied the binary logistic regression model (Eqs. 1–4) (based on Tabachnick and Fidell, 2013) to identify the significant factors that determine the participation of smallholder farmers in SSI activities.

$$Logit(P) = \log\left(\frac{P}{1-P}\right) \tag{1}$$

Let $P_i = \Pr\left(Y = 1 / X = x_i\right)$, then we can write the model as (2)

$$\Pr(Y = 1 / x = \frac{\exp^{x'\beta}}{1 + e^{x'\beta}}; \log\left(\frac{P_i}{1 - P_i}\right) = logit\left(P_i\right) = \beta_0 + \beta_1 x_i \tag{3}$$

P_i is the probability of an individual engaging in SSI (dependent variable), and x_i's are independent variables affecting participation in SSI. Therefore, the parameter β_i gives the *log* odds of those participating in irrigation (when $x_i = 1$). We can write the model in terms of odds as:

$$\frac{P_i}{\left(1 - P_i\right)} = \exp.\left(\beta_0 + \beta_1 x_i\right) \tag{4}$$

The dependent variable is the participation of smallholder farmers in SSI (dummy variable 1 = if participated in SSI; 0 = otherwise), while we used several independent explanatory variables (see Table 2).

2.4.3.2 Problem confrontation index (PCI)

The most significant challenges or constraints (problems) faced while implementing the value addition innovations were analyzed using the Problem Confrontation Index (PCI; Uddin et al., 2014) as PCI = (most important problem*3) + medium problem*2) + (less important problem*1)].

3 Results and discussion

3.1 Descriptive statistics of respondents and their associations with SSI practices

Though a total of 388 household heads were considered as a sample for this study, Due to incomplete responses and some technical problems, the responses of 8 household heads (2.1%) were not included in the analysis. As a result, the responses 380 (97.9% response rate) were included in the analysis. Out of the total respondents, only 27.1% have engaged in SSI, while the remaining 72.9% did not participate in irrigation activities during the study period. The finding implied that the SSI adoption rate in the study area is low compared to its potential.

As shown in Table 3, 380 smallholder household heads (86.1% male-headed while female-headed households were 13.9%) participated in the survey. The great majority are married (83.4%). Crop production (46.8%) and mixed farming (44.5%) are the principal sources of livelihood. In contrast, non-farm sources of livelihood, like petty trading and wage labor, are negligible. As displayed in Table 4, the average age of the surveyed household heads was 50.08 years, while the mean years of schooling was 2.93 years. The average family size, mean land size, and livestock assets were 5.56 individuals, 0.73 ha, and 3.92 TLU, respectively. Sampled respondents should travel 1.91 and 1.54 h on average to get to the nearest market and communication centers, respectively. An average of 1677.4 Ethiopian birr is earned from irrigation activities annually. Being in a productive age and having a relatively large family size might be a good opportunity to participate in SSI if facilities are fulfilled.

Relatively, most of the respondents have better contact with development agents. Around 96.8% of the respondents have their land. The great majority (67.6%) do have training regarding crop production and SSI, while those having training access to climate change adaptation and early warning were found to be less (29.2%). As a means of information, radio and mobile ownership is worth mentioning as one major factor. Around 45.6 and 46.8% of the respondents do have a radio and mobile phone currently working. In the study area, 48.2% of them utilize financial institutions either for credit or saving; 27.9% have income sources from remittance; around 33.2% are members of cooperative associations. Non-farm sources of income were found to be negligible (Figure 2), but around 46.8% replied that income sources besides agriculture might be the income earned from safety net programs and direct humanitarian supports. Around 73.1% of the respondents had faced either partial or total crop failure, 62.6% had received food aid at least once, 72.6% had information regarding climate change, and 62.5% believed climate change could be adapted. The Phi correlation coefficient ($\phi = 0.395$, $p < 0.001$) revealed that having information regarding the impacts of climate change has a moderate effect on believing in its adaptability. Thus, dissemination of information by whatever means would enable smallholder farmers to believe in the possibility of adapting to the impacts of climate change. It would also allow them to undertake feasible adaptation strategies to overcome the effects of climate change and harness opportunities.

As depicted in Table 4, an independent sample t-test was employed to examine whether there is a statistically significant difference between irrigation users and non-users regarding different covariates. The statistically significant mean age difference was found ($t = 3.548$, $p < 0.001$) where irrigation users were found to be younger ($M = 47.37$, $SD = 9.22$) as compared with non-users ($M = 51.08$, $SD = 9.01$). On the other hand, the mean years of schooling for irrigation users were found to be ($M = 4.98$, $SD = 4.45$), which is higher than their counterparts ($M = 2.17$, $SD = 3.38$), and the difference is statistically and significantly different ($t = 6.589$, $p < 0.001$) at 95% level of significance. Another variable where a significant difference was observed in total land holding, where households having relatively better land holding ($M = 0.8648$, $SD = 0.344$ for users and $M = 0.6735$, $SD = 0.28$ for non-users) were found to be irrigation users with a

TABLE 2 Covariate and their association with the adoption of SSI.

Dependent variable		
Small-scale Irrigation Adoption		1 = if the household head had implemented small-scale irrigation during the time of the interview; 0 = otherwise
Independent variables		
No	**Covariates**	**Type of influence in the adoption of SSI**
1	Education level of the household head (HHH)	The capacity of individuals to obtain, process, and utilize information from different sources is mainly regulated by their educational level. Educated farmers are more likely to have relatively better access to acquire, analyze, and evaluate information on modern technology as well as market opportunities than others, which might encourage the adoption of irrigation (Feyisa, 2020; Zegeye et al., 2022; Gemeda et al., 2023)
2	Headship type	Much of the outdoor farming activities in developing countries are done by males, while females are more involved in home chores (Teha and Jainjun, 2021; Geddafa et al., 2021). Women shoulder almost all household chores and have minimal time left for adaptations and engaging in remunerative activities (Nigussie et al., 2014; Mare, 2017). Women are constrained with access to credit, inputs, extension services, and information, which are vital in undertaking adaptations (Mare, 2017)
3	Age of the HHH	As the farmer's age increases, their adoption will decrease or increase. Due to the risk-averting and conservative nature, older farmers were found to be less inclined to try new practices; instead, younger ones exposed to new agricultural technologies were better at adopting technologies because they were more aware of the benefits of adoption in enhancing productivity than their counterparts. On the contrary, young farmers may have more formal education than the non-adopters, are less risk averse, more willing, have greater flexibility in accepting new ideas, and are more likely to adopt new technology (Teha and Jianjun, 2021; Zegeye et al., 2022; Gemeda et al., 2023). Feyisa (2020) argued that older farmers, due to their awareness of the benefits of technologies (as a result of their experience) and the high possibility of having larger farm sizes and asset endowments, are better at adopting agricultural technologies
4	Farm size	Farmers with larger farm sizes might allocate part of their land for irrigation than those who have smaller plots of land (Challa and Tilahun, 2014; Feyisa, 2020; Gemeda et al., 2023)
5	Accesses to training, extension services, and information	Farmers who have more access to these services have more exposure to information on new agricultural technologies, which enhances the extent of adoption. Provision of up-to-date information, extension services, and training play a fundamental role in the dissemination of information, raising awareness, developing skills, and building the confidence of farmers to adopt new technologies (Feyisa, 2020; Challa and Tilahun, 2014; Asmera and Yidnekachew, 2021; Zegeye et al., 2022).
6	Livestock asset in TLU	Farmers who possess high livestock assets do have the economic freedom to secure agricultural inputs and are more likely to adopt technologies, including SSI, than the have-not (Feyisa, 2020; Zegeye et al., 2022)
7	Credit access	Access to credit enables farmers to meet transaction costs associated with various adaptation options (technologies and inputs) and timely application of farm inputs. Access to credit solves liquidity constraints that farmers could face when they want to buy agricultural technology packages (Challa and Tilahun, 2014; Feyisa, 2020; Asmera and Yidnekachew, 2021; Teha and Jianjun, 2021; Ngango and Hong, 2021; Geddafa et al., 2021; Zegeye et al., 2022)
8	Distance from the market and nearby urban centers	Farmers close to the main road or market centers have better access to transportation facilities and better support from concerned bodies, can buy selected seeds and inputs, and have better information, which might increase the likelihood of using new technologies. Most irrigation products are perishable and need market and transportation access. Farmers who live away from markets and urban centers are less likely to adopt irrigation due to less access to information and high production/transaction costs (Challa and Tilahun, 2014; Feyisa, 2020; Zegeye et al., 2022)
9	Cooperative membership	Being a cooperative member as a social capital creates a conducive environment to get market information, credit access, and knowledge spillover. As a result, it enhances the propensity to adopt SSI (Feyisa, 2020; Ngango and Hong, 2021).
10	Wealth Status (income from on/non-farm sources	Wealthier farmers are more likely to adopt technologies because they can cover the required expenditures of the new technology under consideration. Households with additional income from non/off-farm activities are better endowed with additional income to secure essential agricultural inputs and technologies (Challa and Tilahun, 2014; Zegeye et al., 2022).
11	Family size	Since participating in irrigation requires more labor force and shares the labor resources engaged in other activities, households with large family sizes are more likely to adopt SSI (Asmera and Yidnekachew, 2021; Geddafa et al., 2021; Zegeye et al., 2022). Conversely, family size also negatively affects adoption because more family members within the household may weaken their economic status, and adoption decreases (Sahu and Das, 2016).
12	Remittance	Both negative and positive associations are reported regarding the impact of remittance income on technology adoption. Families having income from remittance might use it for daily consumption rather than investing in agricultural development (Zegeye et al., 2022). On the other hand, households with higher remittance inflows might have higher income buffer and solve liquidity constraints to secure agricultural technologies and inputs and participate in SSI (Mohammed, 2014)
13	Extension and Advisory service	Extension and advisory services provided by different agents to the farmers affect the decision to adopt positively because they provide information, training, and advisory services about the sources and contribution of the technologies to the farmers participate in input distribution, and play a significant role in the dissemination and adoption of farm technologies. Regular interactions with extension agents raise the likelihood of acquiring up-to-date information about SSI (Asmera and Yidnekachew, 2021; Geddafa et al., 2021).

(Continued)

TABLE 2 (Continued)

14	Non/off-farm income source	Non/off-farm activities affect the adoption decision since engagement in off-farm activities reduces the working hours allotted to agriculture (Mume et al., 2023). Conversely, it could positively affect the adoption decision because participating in Non/off-farm activities can generate income and solve the liquidity constraints of the farmers to secure essential agricultural inputs (Mulugeta and Hundie, 2012).
15	Land ownership and tenure security	Ownership and security right of plots positively affects the probability of small-scale adoption because having full ownership rights will help the farmers to make a long-term investment and may have no additional cost (as rented), which encourages farmers to produce more by applying different farm technologies (Mohammed, 2014)
16	Plot Distance	Distance from home to farm plot negatively affects the probability of adoption as the plot of the household is distant from the farmhouse, the less likely will be prompt plot preparation, weed, harvest, and input use (Asmera and Yidnekachew, 2021 Geddafa et al., 2021; Zegeye, 2021).
17	Having administrative responsibility	Having responsibility in the administrative system would enable the development of good social capital and social trust. This, in turn, plays triple prominent roles: in the adoption of different climate change adaptations by acting as a means for financial transfers that may overcome farmers' credit constraints, as a source of information about new technology, and as a means to facilitate cooperation in collective action (Mume et al., 2023).

TABLE 3 Descriptive statistics of sample respondents.

Variables	Category	N (%)
Type of household head (*N* = 380)	Male	327 (86.1)
	Female	53 (13.9)
Marital status of the household head (*N* = 380)	Single	2 (0.5)
	Married	317 (83.4)
	Divorced	28 (7.4)
	Widowed	33 (8.7)
Principal source (s) of livelihood (s) for the household (*N* = 380)	Crop production	178 (46.8)
	Animal husbandry	29 (7.6)
	Mixed farming	169 (44.5)
	Petty trading	1 (0.3)
	Wage laborer	3 (0.8)

Source: Survey, 2021.

TABLE 4 Descriptive statistics of continuous variables across adopters (*N* = 103) and non-adopters of small-scale irrigation (*N* = 277).

Variables code	Participants		Non-participants		*t*-test	Overall	
	Mean	SD	Mean	SD		Mean	SD
HHHAGE1	47.37	9.22	51.08	9.01	3.548***	50.08	9.209
HHHEDUCTN l	4.98	4.45	2.17	3.38	−6.589***	2.93	3.898
THHStotal	5.99	1.32	5.04	1.27	−6.43***	5.56	1.378
LANDHA	0.865	0.034	0.674	0.28	−5.611***	0.73	0.307
TLU	5.38	2.89	3.37	2.17	−6.421***	3.92	2.542
DISTMRKT	1.639	0.95	2.017	1.323	2.644**	1.91	1.25
DISTCMMC	1.27	0.90	1.64	1.04	3.157***	1.54	1.01

Source: Computed from Own survey, 2021.
***Statistically significant at 99% level of significance.
**Statistically significant at 95% level of significance.

statistically significant mean difference in land size at 95% significance level ($t = 5.611$, $p < 0.001$). Similarly, households that have a better size of TLU assets were found to be irrigation users than their counterparts ($M = 5.38$, $SD = 2.89$ for users and $M = 3.37$, $SD = 2.17$ for non-users), and the mean TLU difference was statistically significant ($t = 6.421$, $p < 0.001$). Distance from nearby markets was another variable that showed a statistically significant mean difference where those having closest proximity to market centers were found to be more irrigation users ($M = 1.639$, $SD = 0.951$ for users and $M = 2.017$, $SD = 1.33$ for non-users) and ($t = 2.644$, $p < 0.005$). A statistically significant

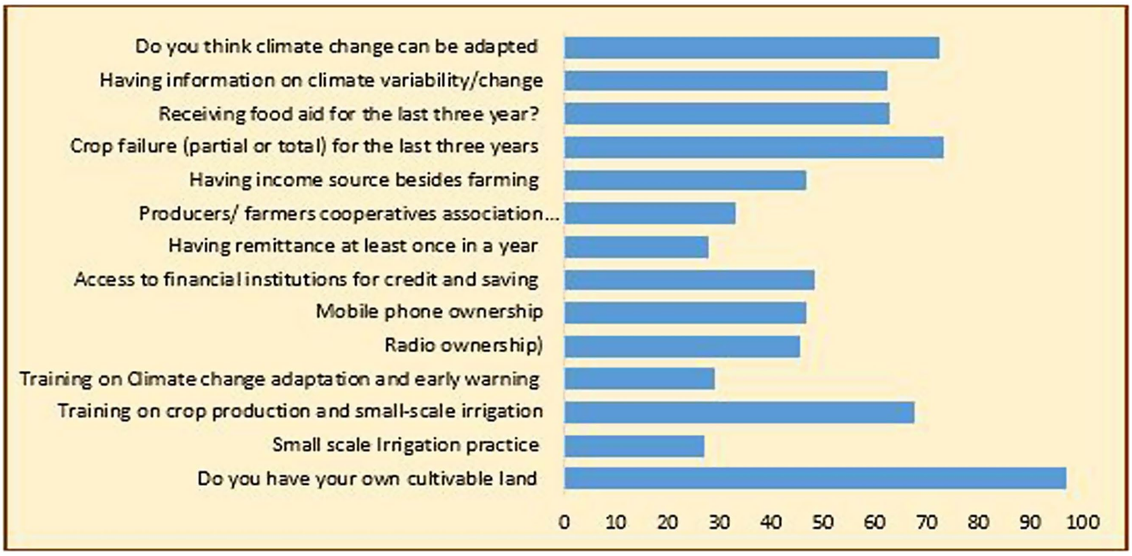

FIGURE 2
Descriptive percentages (Yes) of Respondents on different attributes.

difference in terms of family size was also observed ($M = 5.99$, $SD = 1.32$ for users and $M = 5.04$, $SD = 1.27$ for non-users) and ($t = 6.43$, $p < 0.001$). Generally, the younger, those with better educational status, those households with larger family sizes, those with relatively better land holding and livestock assets, and those residing close to market areas were found to be irrigation users more than the other way round. The Chi-square result revealed that the likelihood of participating in SSI activities is higher for those who are microfinance beneficiaries, those who have remittance income sources, cooperative members, heads having responsibility in kebele, those who believe that climate change is adaptable, those who reside in upper and middle-lands, those having radio (source of information), having training exposure on SSI and having non-farm income sources. The proportion difference was statistically significant at a 95% significance level (see Table 5 for details).

3.2 Typologies of SSI and major constraints

Figure 3 depicts the top three most commonly practiced irrigation types during data collection: river or stream diversion, night storage, or using nearby springs, and underground water or hand-dug wells. Rainwater harvesting, small-scale dams, and motor pumping are also practiced to a lesser extent. Most of the irrigation types being implemented are not water efficient. Drip irrigation and similar water-efficient irrigation technologies are not practiced at all. An interviewed irrigation expert from the Borena Woreda agricultural office stated that most of the irrigation practices practiced in the Woreda are traditional and not water-efficient by nature. During field observation, we observed a furrow irrigation (Figure 4) where a significant amount of water was wasted. Such irrigation modalities are not recommended where water scarcity is among the significant challenges partially caused by climate change.

An interviewed farmer agreed that such irrigation modalities are not water efficient, and according to the respondents, modern irrigation technologies are not affordable. Besides, for small plots of land, securing modern irrigation technologies at a high cost is not profitable from the point of view of economies of scale. As shown in Figure 4, the irrigation practice in the study was constrained by water scarcity, shortage of land, shortage of labor, and shortage of modern inputs. As shown in Figure 5 and observed during field observation, most SSI products are marketable fruits and vegetables. According to one interviewed farmer, sales of fruits and vegetables are crucial in helping cover various costs.

Interviewed farmers engaged in irrigation cited water scarcity as their main critical problem. They added that most water sources have decreased in volume, and farmers are forced to apply rationing methods for their irrigation fields. Another critical constraint mentioned by the district agricultural office's interviewed farmers and experts is a land shortage. The district is among the highly populated areas of the region where land *per capita* is minimal. As a result, devoting a certain proportion of land to irrigation is challenging for most farmers. Furthermore, the traditional irrigation system is labor-demanding. So, the shortage of active labor force was another challenge in the study area (Figure 6). In addition, one of the critical issues raised during the interview was the lack of technical expertise regarding the installation, utilization, and maintenance of modern pumping. Almost all key informant participants agreed that the lack of a market for their products is not a problem (most constraints are from the supply side, not the demand side).

3.3 Determinants of SSI utilization

We employed a logistic regression model to estimate the factors that determine farmers' participation in SSI. Multicollinearity diagnosis for continuous explanatory variables and degree of association for discrete variables were inspected using VIF, tolerance statistics, and the contingency coefficient. The maximum VIF and contingency coefficient found were 1.602 and 0.32 (see Annex 1),

TABLE 5 Descriptive statistics of the discrete variables across adopters ($N = 103$) and non-adopters ($N = 277$).

Variable	Category	Irrigation practice		χ^2 statistic	p-value
		Participants	Non-participants		
Type of household head	Female-headed (53)	12	41	0.621	0.431
	Male headed (327)	91	236		
Microfinance utilization	No (197)	31	166	26.76	0.000
	Yes (183)	72	111		
Remittance	No (274)	53	221	29.95	0.000
	Yes (106)	50	56		
Cooperatives membership	No (254)	54	200	13.25	0.000
	Yes (126)	49	77		
Responsibility in Kebele	No (259)	53	206	18.16	0.000
	Yes (121)	50	71		
Climate variability is adaptable	No (104)	19	85	5.75	0.017
	Yes (275)	84	191		
Location	Upper-land (129)	38	91	14.38	0.001
	Middle-land (143)	50	93		
	Lower-Land (108)	15	93		
Training on SSI	No (123)	21	102	9.264	0.002
	Yes (257)	82	175		
Training on climate change adaptation and early warning	No (269)	66	203	3.07	0.079
	Yes (111)	37	74		
Do you have your radio currently operating?	No (206)	32	174	30.911	0.001
	Yes (173)	71	102		
Do you have a mobile phone currently operating?	No (202)	31	171	30.18	0.001
	Yes (178)	72	106		
Do you have a non-farm source of income?	No (199)	42	157	7.51	0.006
	Yes (175)	59	116		

Source: Computed from Own survey, 2021.

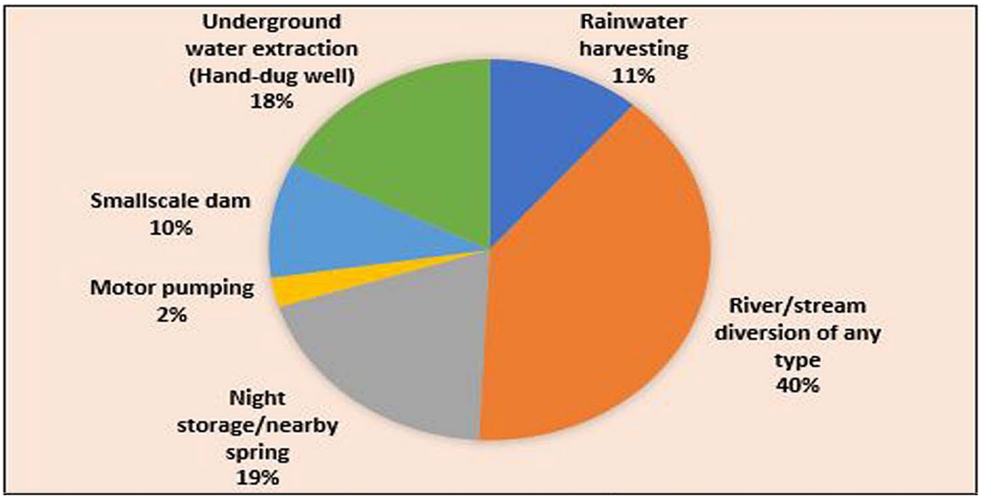

FIGURE 3
Major Irrigation Typologies (Source: Drawn from own survey, 2021).

FIGURE 4
Major types of irrigation in the study area (motor pumping, small-scale dam, and furrow irrigation; photo from Borena Woreda Agricultural Office, 2023).

FIGURE 5
Major types of products produced using irrigation (fruits and vegetables; photo from Borena Woreda Agricultural Office, 2023).

respectively (both are below the required threshold to consider the multicollinearity problem), which evidenced the appropriateness of the independent variables for running binary logistic regression. Correlation tests and contingency coefficients were used to screen out variables strongly associated with the dependent variable. Five variables with a correlation coefficient below 0.3 were omitted from the analysis. Accordingly, 17 variables (out of 22 candidate variables), assumed to be associated with the participation of smallholder farmers' irrigation strategies, were included in the model (see Table 6). Among the variables, eight were statistically significant at 0.05 alpha level.

The model classification ascertained the model's goodness-of-fit, where 84.8% of respondents were correctly classified by the model (72.6% in the constant-only case). The Omnibus Tests and −2 log-likelihood ratio test revealed that the estimated model, including a constant and the set of explanatory variables, fit the data better than

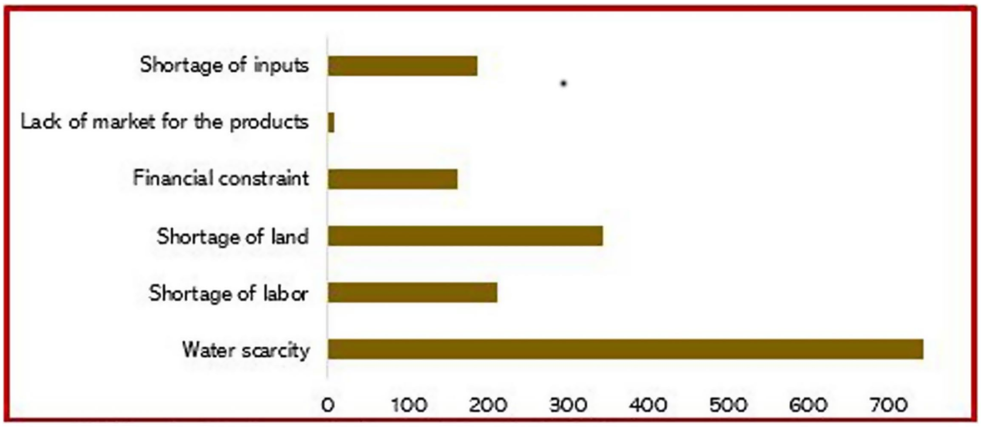

FIGURE 6
Constraints in practicing small-scale irrigation.

TABLE 6 Binary Logistic regression model result on determinants of irrigation users.

Covariates	B	S.E.	Wald	Sig.	Exp(B)
HHHEAD	−1.401	0.520	7.248	**0.007**	0.246
HHHEDUCTN	0.214	0.050	18.069	**0.000**	1.239
HHHAGE1	−0.057	0.022	6.906	**0.009**	0.945
Location			16.257	0.000	
location(2)	2.029	0.672	9.112	**0.003**	7.605
location(3)	2.634	0.654	16.206	**0.000**	13.929
TRNING11	−0.368	0.452	0.661	0.416	0.692
TRNING17	0.300	0.373	0.645	0.422	1.349
INFORMED	−0.189	0.419	0.205	0.651	0.827
DISTMRKT	0.145	0.221	0.428	0.513	1.156
THHStotal	0.661	0.142	21.79	**0.000**	1.936
LANDHA	2.153	0.702	9.409	**0.002**	8.609
TLU	0.134	0.087	2.371	0.124	1.144
MCROFN	0.274	0.353	0.605	0.437	1.316
ASSOCTN	0.488	0.353	1.914	0.167	1.629
HUSRESPN22	0.727	0.350	4.320	**0.038**	2.069
NONOFFRM	−0.289	0.369	0.613	0.434	0.749
CROPFLR1	−0.944	0.427	4.875	**0.027**	0.389
RMTTNCE	0.037	0.372	0.010	0.921	1.038
Constant	−4.766	1.717	7.709	0.005	0.009
Number of obs = 369; Prob > chi^2 = 0.000; Pseudo R^2 = 0.53; Overall predictivity power (84.8%)					

Source: Computed from Own survey, 2021. HHHEAD (Headship type = 1-male. 0 otherwise); HHHEDUCTN (Educational level completed by the household head in grade level); HHHAGE1 (Age of the household head in years); Location (Relative location of the respondents = 1 = upland; 2 = midland, 3 lower land); TRNING11 (Having training access on crop production = 1 = yes, 0 = otherwise); TRNING17 (Having training access on climate change = 1 = yes, 0 = otherwise); INFORMED (having information regarding acess = 1 yes, 0 = otherwise); DISTMRKT (Distance from the nearby market center in hours); THHStotal (Total household size in number); LANDHA (Total land asset in hectare); TLU (Total livestock assets in TLU); MCROFN (Microfinance access = 1 = yes, 0 = otherwise); ASSOCTN (Being a member of producers/farmers cooperatives association = 1 = yes, 0 otherwise); HUSRESPN22 (Having responsibility in the district = 1 = yes, 0 = otherwise); NONOFFRM (Having a non-farm source of income = 1 = yes, 0 otherwise); CROPFLR1 (Encountered crop failure (1 = yes, 0 otherwise); and RMTTNCE (Having remittance income = 1 = yes, 0 otherwise. The bold sig. values are statistically significant at 0.05 alpha level.

the model containing only the constant. This suggests a stronger correlation exists between the odds ratio (or log of odds), the likelihood that a particular factor will influence a farmer's decision to participate in irrigation, and the explanatory variables in the model. These factors significantly contribute to explaining smallholder farmers' influence in adopting SSI. The overall estimated model has remarkable explanatory power, although some coefficients were insignificant when considered individually. The highly significant Chi-Square result, the overall percentage of correct prediction, and the Pseudo R^2 value (Cox and Snell's of 0.366 and Nagelkerke of 0.53) all support this claim.

Moreover, a non-significant result of the Hosmer-Lemeshow goodness-of-fit test ($\chi^2 = 12.741$, $p = 0.121$, $df = 8$) revealed the model's appropriateness (well–fitting). Using the VIF and tolerance statistics, multicollinearity diagnosis for continuous explanatory variables was also examined. The outcome showed no issues with multicollinearity among the explanatory variables. Furthermore, the degree of association between each dummy/discrete variable was also assessed using the contingency coefficient. The estimated coefficients of the logit model are presented in Table 6. As indicated by the χ2 statistic, the likelihood ratio statistics is significant at 1%. This suggests that all the variables in the logit model are jointly significant in influencing smallholder farmers' decision to partake in irrigation activities. Finally, adoption probability is estimated using the Adjusted Odd Ratio (AOR).

The educational level of the household head is among the factors determining the adoption of SSI (Ngango and Hong, 2021). As predicted, it was found that the head of the household's education has a positive and significant effect at the 0.05 alpha level, suggesting a positive relationship with the adoption of irrigation. This indicated that, compared to their peers, household heads with greater levels of education are more inclined to practice SSI. If all else remains equal, an additional year of education could raise the likelihood that smallholder farmers will use irrigation by 1.239% (Table 6). This result is consistent with Belete and Melak (2018), Zegeye et al. (2022), and Gemeda et al. (2023). If they receive education, smallholder farmers may be better equipped to process and apply vital information from various sources. Higher-educated people are more inclined to adopt new technology since they understand their relevance better. Besides, they can look at market opportunities and have a better likelihood of taking calculated risks. Higher educated farmers are more likely to choose better adaptation strategies in response to climate change; they have a greater degree of knowledge and are therefore more able to comprehend and respond to changes that are anticipated; they are more adept at predicting future scenarios; and, overall, they typically have access to opportunities and information that may encourage climate change adaptation (Kumasi et al., 2017).

The sex of the household head is worth mentioning as a determinant factor in technology adoption, favoring male-headed ones. In this study, the likelihood of female-headed households participating in SSI activities is statistically and significantly lower than (24.6%) male-headed ones at a 95% significance level (Table 6). The finding coincides with Teha and Jainjun (2021) and Zemarku et al. (2022). This might be due to a difference in information, extension, and asset access, where males are better than females. Besides, women are more engaged in household chores like cooking and childcare activities; in most cases, they are endowed with fewer resources and less exposed to new information, which hampers their adoption rate of new technologies. Gender plays a role in adaptation decisions (man-headed households often implement some adaptation strategies). Since women are more involved in household chores and men perform a significant portion of outdoor farming activities in developing nations, male-headed households have greater access to farming experience and knowledge of various adaptation strategies (Nigussie et al., 2014). A study in Ethiopia found that women handle almost all household chores, leaving little time for repairs or other financial activities (Nigussie et al., 2014; Mare, 2017).

Moreover, Mare (2017) has shown that women in Ethiopia encounter obstacles when obtaining loans, inputs, extension services, and information—all essential when undertaking adaptations. The female participant in KII, age 52, holds a distinct perspective. This respondent says that having a male or female head of household is not a significant obstacle; instead, because traditional irrigation methods are labor-demanding, it is more important to have an active labor force in the family. Irrigation activities are common among families with more productive labor forces.

By its nature, SSI practice is a laborious activity where younger ones are expected to be engaged more. The impact was statistically significant at a 95% significance level. As predicted, the probability of SSI declines with household age. The likelihood of participation decreases by about 9.45% when the age increases by 1 year (Table 6). A similar finding was reported by Teha and Jianjun (2021), Zemarku et al. (2022), and Gemeda et al. (2023). The reason for the inverse relationship between adoption and age is that older farmers are less likely than younger farmers to adopt new agricultural technologies because they are risk-averse and conservative. However, our finding differs from Feyisa (2020), where a positive association was reported.

Location is another covariate considered a possible factor affecting the probability of households' engagement in irrigation, mainly due to differences in the availability of resources. In this study, location was found to significantly affect the likelihood of participation in SSI, where households in middle and upper lands participated more in irrigation than those residing in the lower lands due to better availability of water resources and rainfall amount. The probability of households in the middleland and upper-land participating in SSI was 13.929 and 7.605% more likely than those living in the lower-land, respectively, at a 95% significance level (Table 6). Our finding corroborates with Geddafa et al. (2021), Zemarku et al. (2022), and Zegeye et al. (2022). This negative association implies that the farther the plot of land, the lesser would-be farmers' initiative to participate in SSI due to the opportunity cost of training to and from an irrigation plot, and proper surveillance of the farm activities might be challenging when distance increases from the homestead.

SSI activity is labor demanding sector. At the 95% significance level, the size of the entire household influenced people's participation in small-scale activities. Participation probability increases at 1.936% when family size increases by one unit (Table 6). The result is consistent with Geddafa et al. (2021), Zegeye et al. (2022), Zemarku et al. (2022), and (Gemeda et al., 2023) that reported a positive relationship between the labor force of a family and the propensity of adopting irrigation. Having a larger family size encourages participation in diversified activities, including irrigation. A different result was revealed by Challa and Tilahun (2014), where family size was negatively and significantly associated with the rate of adoption. Although the relationship between family size and the adoption rate of agricultural technology adoption is not clear-cut, it is reasonable to assume that a large labor force may accelerate the adoption rate of labor-intensive technologies. As SSI participation requires more labor, a household with a more significant labor force is more likely to adopt irrigation than one with a smaller labor force. In countries like Ethiopia, family labor is among the most widely utilized inputs for irrigation. It is primarily used for plot preparation, canal construction, diverting water from rivers, weeding, watering, and other purposes. As a result, households with a higher labor force are more likely to adopt irrigation than households with a smaller labor force, and SSI participation requires more labor.

Land size matters for diversifying income sources in rural areas. The participation of households with better land size was higher, and the result was statistically significant at a 95% significance level (Table 6). An increase in land size by 1 hectare increases the likelihood of engagement in irrigation by about 8.609%, *citreous paribus*. A similar finding was reported by Challa and Tilahun (2014), Belete and Melak (2018), Feyisa (2020), and Gemeda et al. (2023). More productive and profitable households may arise from better arable land and be more likely to embrace new agricultural technologies. Furthermore, it might be possible to distribute failure risks with increased farmland. Both interviewees concurred that the district's meager land *per capita* makes it difficult for farmers to diversify their agricultural operations, including setting aside a portion of their land for irrigation. Having responsibility in local administration exposed individuals to better information regarding market and capital, which, in turn, encouraged them to participate in income-generating activities like irrigation. Keeping all other factors constant, being a member of local administration has increased the probability of engagement in irrigation by 2.069% at a 95% significance level (Table 6). Having responsibility in local administration creates social capital and trust to secure input, information, and finances, which are crucial in increasing the probability of participation in SSI. A similar finding was reported by Feyisa (2020) and Ngango and Hong (2021). The plausible reason is that participation in local leadership can help to have more access to financial resources and information, share experiences with others, and create a more social network. Our result differs from Teha and Jianjun's (2021), where a non-significant relationship between social association membership and SSI adoption was reported.

On the other hand, the incidence of crop failure due to different factors discourages farmers from engaging in crop production and might shift towards non-farm income sources. We found that the likelihood of engaging in irrigation decreased by about 38.9% whenever the household faced crop failure problems (Table 6). Our result is in line with the findings of Ngango and Hong (2021) and Gemeda et al. (2023), where individuals who faced crop failure due to climate-related hazards and those who perceived similar risks tend to shift into non-agricultural activities. This probably might be due to a shift into non-farm activities whenever there is frequent crop failure, which discourages smallholder farmers and tends to participate in non-agricultural sources of income as a risk aversion strategy. The impact of most institutional factors (training, radio ownership, distance from market, microfinance access, association, having non-farm income source, remittance, TLU) was found non-significant in the study area through hypothesized to have positive impacts in determining the likelihood of participation of farmers in irrigation activities.

4 Conclusion and policy implication

Food security and agricultural productivity are threatened by climate change, particularly in areas with limited water resources and unpredictable rainfall. SSI is a promising adaptation strategy to address these challenges and enhance agricultural communities' resilience. It increases water use efficiency, enhances crop yield, diversifies crops, and empowers smallholder farmers. By implementing supportive policies and capacity building, governments can empower farmers and improve agricultural resilience by expanding SSI in a changing climate. Based on these arguments, we tried to estimate the factors regulating SSI in one of the drought-affected areas of Ethiopia using a binary logistic regression model. The primary irrigation modality implemented in the study area is the traditional furrow irrigation system, mainly through river diversion. Such irrigation systems are not water efficient and are labor-demanding. Water-efficient and labor-saving irrigation technologies are rarely utilized due to their affordability and limited technical know-how, mainly in installation and maintenance. The study area is among the most populated areas of the country, where land *per capita* is small. Non-farm sources of livelihood are rare, whereas rainfed agriculture is the predominant livelihood type. Though training given regarding SSI is relatively better, those having training access on climate change adaptation and early warning were found to be less. The principal problems mentioned while practicing SSI are water scarcity, lack of land, and shortage of active labor force.

Based on the independent samples *t*-test and Chi-square test results, households with larger family sizes, younger farmers with higher educational levels, relatively better land holding and livestock assets, and those close to market areas were more likely to use irrigation than the opposite. Furthermore, people who believe that climate change is adaptable, live in upper and middle-class areas, have access to radios as a source of information, have received training on SSI, have non-farm income sources, are cooperative members, heads of kebeles with responsibilities, and are beneficiaries of microfinance are more likely to engage in SSI activities. The binary logistic regression model's findings confirmed that the main determinants of the adoption rate of SSI are headship type, the household head's educational attainment, age of the head, relative agroecological location, farmland size, family size, and administrative responsibility in the local community where the interplay of economic constraint and innovation-diffusion model seems more influential in the study area.

Our findings have several policy implications. Most irrigation modalities practiced in the study area are traditional, not water-efficient, or laborious. As a result, government and development agencies should provide financial support, particularly for resource-constrained farmers, to purchase and install water-efficient and labor-saving irrigation technologies. Ensuring SSI technologies' effective utilization and sustainability requires farmers to receive training and extension services on their design, operation, and maintenance. It was discovered that believing in the adaptability of climate change was correlated with knowing its effects. Therefore, increasing SSI as a viable option for adapting to climate change would require timely information for small-scale farmers. Further intervention conserving SSI and climate change adaptation strategies should consider the factors regulating the adoption rate of different strategies.

4.1 Limitation of the study

Since the study depends on cross-sectional data, it did not enable the examination of the dynamism through time and limits the control of selection bias due to problems of unobserved heterogeneity. As a result, further research with panel data is recommended to better capture the effects of irrigation over time. Future research should pay particular attention to the impacts of irrigation on income, poverty level, consumption expenditures, and food security status. Besides rigorous irrigation potential assessment, GIS and remote sensing techniques are essential.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Before conducting the study, written permission was obtained from South Wollo zonal administrative offices. During the survey, an official letter was written from the district agricultural office; informed verbal consent was obtained from each respondent (survey participants), while written consent was secured from key informant participants. Besides, confidentiality was maintained by giving codes to each respondent rather than recording their name. Study participants were informed that they had full rights to discontinue or refuse to participate. Hence, all participants throughout the research, including survey households, enumerators, supervisors, and key informants, were fully informed of the study's objectives. Besides, the study complies with all the necessary research regulations and ethical considerations.

Author contributions

AAE: Methodology, Writing – original draft, Writing – review & editing. AAM: Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Annex

ANNEX 1 Multicollinearity statistics for continuous variables.

Continuous variables	Collinearity statistics	
	Tolerance	VIF
Age of the household head in years	0.764	1.309
Maximum class level completed by the household head	0.697	1.434
Total family size	0.913	1.095
Total farm size in hectare	0.682	1.466
Tropical Livestock Unit (TLU)	0.624	1.602
The average time (on foot) to reach the nearest major market center (one way round) in hours is	0.966	1.035