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Adoption of small-scale irrigation pathway for rural food security: Key determinants and coping strategies in Ethiopia

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Abstract

Food insecurity remains a critical challenge in Sub-Saharan Africa despite favorable natural conditions. In Ethiopia, rural households continue to face persistent food shortages, yet evidence on how small-scale irrigation affects food security at the household level remains limited. This study assessed the food security status and coping strategies of households in the rural areas of Wolaita Zone, southern Ethiopia. Primary data were collected from 130 households through a cross-sectional survey and analyzed using descriptive statistics and a Binary Logistic Regression model. Results showed that 56.15% of households were food insecure, while 43.85% were food secure. Household food security was significantly influenced by family size, age of household head, access to markets, education level, and livestock ownership. Coping strategies varied by severity: at initial stages, households relied on labor migration, social support, credit purchases, and asset sales, while at severe stages, they turned to food-for-work programs, distress livestock sales, school dropout, food aid, and sale of production equipment. The study contributes localized evidence on the role of irrigation in enhancing food security and reducing reliance on negative coping strategies. Findings highlight the need for policies that promote small-scale irrigation adoption, strengthen market access, and support diversified livelihood strategies for rural poor households.

Keywords: Binary Logit Model; Key factors; Coping strategies; Food Security; Small-scale irrigation

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1. Introduction

Food is a fundamental human necessity and is the cornerstone for survival, economic development, and social well-being (Borku et al., 2024a; Kunwar, 2017). In the context of Ethiopia's development agenda, the government has prioritized addressing food security issues, particularly in rural areas (Eneh, 2021). Food security is a flexible and evolving concept, as reflected in the various attempts to define it within research and public policy. Recognizing the technical and policy complexities involved has shaped the continued development of food security as an operational concept in public policy (Borku et al., 2024a; Borku et al., 2024b).

Globally, food security remains a pressing challenge, with millions suffering from hunger and malnutrition. According to the State of Food Security and Nutrition in the World report (FAO, 2023), nearly 2.4 billion people globally face moderate or severe food insecurity, particularly in developing regions. Sub-Saharan Africa bears the heaviest burden, accounting for more than 20% of the world's food-insecure population (Borku et al., 2024a). The region's vulnerability is driven by many factors, including erratic climatic conditions, rapid population growth, poor agricultural productivity, and socio-economic instability Masha et al., 2021). Chronic food insecurity is exacerbated by a reliance on rain-fed agriculture, which is highly susceptible to climate variability, making sustainable food production a significant challenge (Ngcamu & Chari, 2020).

In Africa, agriculture remains the backbone of most economies, employing up to 60% of the workforce and contributing significantly to household incomes (Borku, 2025). However, smallholder farmers, who make up the majority of agricultural producers, face numerous challenges such as limited access to modern technologies, market constraints, and land degradation (Diao et al., 2023). These challenges are further compounded in hunger-prone areas, where rural households are often forced to adopt unsustainable coping strategies during food shortages. As such, addressing food insecurity requires innovative and localized solutions, such as the promotion of small-scale irrigation systems to ensure stable and improved agricultural yields. Small-scale irrigation has proven effective in mitigating the impacts of climate variability, reducing dependence on seasonal rainfall, and enhancing crop productivity (Cifdaloz et al., 2010; Assefa et al., 2018; Shitu & Almaw, 2020). Despite its potential, the adoption of small-scale irrigation systems remains limited in many parts of Africa due to financial, technical, and socio-cultural barriers (Diao et al., 2023).

Ethiopia, one of the largest economies in Sub-Saharan Africa, exemplifies this continental challenge. Despite its vast natural resources and favorable agro-climatic conditions, Ethiopia continues to grapple with chronic food insecurity, particularly in rural areas (Assefa & Abide, 2022). This challenge has persisted due to various factors, including climate change, land degradation, population pressure, and low agricultural productivity (Singh, 2019; Zewdie et al., 2020). The country's agricultural sector, which supports approximately 80% of the population, remains predominantly rain-fed and highly vulnerable to environmental shocks, such as droughts and erratic rainfall patterns (Borku et al., 2024a). Ethiopia, as a country in this region, reflects these broader challenges, where rural households remain highly vulnerable to food insecurity due to their dependence on subsistence farming and unreliable rainfall. Despite the government's efforts to address food insecurity through agricultural development programs and irrigation projects, progress remains slow, particularly in hunger-prone areas like the Wolaita Zone. In regions such as the Wolaita Zone in southern Ethiopia, recurrent droughts, population pressure, and fragmented landholdings have worsened food insecurity, leaving rural households at the mercy of unpredictable climatic conditions. Although small-scale irrigation offers a pathway to enhance food security, its adoption in hunger-prone regions remains insufficient, largely due to a lack of infrastructure, financial constraints, and limited awareness among smallholder farmers.

The Damota district in Wolaita Zone exemplifies Ethiopia's broader food security challenges. Rural households in this district face severe food insecurity, driven by recurrent droughts, limited agricultural inputs, poor infrastructure, and high population density (Mota et al., 2019; Cholbe et al., 2020; Mengistu et al., 2021). While small-scale irrigation systems have the potential to stabilize and increase agricultural productivity by mitigating dependence on rainfall, their adoption among smallholder farmers remains low. This raises critical questions about the factors influencing the uptake of small-scale irrigation and its impact on food security in rural communities. Moreover, food-insecure households often resort to short-term and unsustainable coping strategies during times of food shortages, such as selling assets, withdrawing children from school, borrowing money, or seeking food aid (Borku et al., 2024b). These strategies may alleviate immediate hunger but come at the cost of long-term resilience, pushing households further into poverty. Without a comprehensive understanding of the determinants of food security, the adoption of small-scale irrigation, and the coping mechanisms employed by rural households, policymakers and development agencies may struggle to implement effective interventions that address both the immediate and systemic drivers of food insecurity. Therefore, this study is both necessary and timely. While previous research has examined irrigation and food security at national or regional scales, there is limited localized and household-level evidence from hunger-prone areas such as the Wolaita Zone. This article is innovative in that it combines (i) a calorie-based measurement of food security, (ii) an analysis of the determinants of small-scale irrigation adoption using a Binary Logistic Regression model, and (iii) an exploration of the coping strategies of food-insecure households across different stages of food shortages. By integrating these three dimensions, the study contributes new insights into how irrigation can reduce vulnerability and strengthen resilience among rural households in one of Ethiopia’s most food-insecure districts.

2. Materials and Methods

2.1. Description of the study area

The Wolaita Zone in southern Ethiopia encompasses several hunger-prone areas, including Damota districts such as Bolosso Sore, Damot Gale, and Soddo Zuria (Borku et al., 2024a). Geographically, the zone lies between 6º44'30" to 7º9'49" N latitude and 37º34'47" to 37º98'58" E longitude, covering an estimated 97,600 hectares (Masha et al., 2021). The terrain is rugged and elevated, shaped largely by tectonic and volcanic activities. According to the Ethiopian agro-climatic classification, the area falls within the Woina Dega and Dega zones, with altitudes ranging from 1,480 to 2,855 meters above sea level (Figure 1).

Meteorological records from the Ethiopian Meteorology Institute (2022) indicate that the zone receives a long-term average annual rainfall of about 1,100–1,300 mm, distributed in a bi-modal pattern. The main rainy season (Kiremt) occurs from June to September, while the short rainy season (Belg) takes place from February to March. The mean monthly minimum and maximum temperatures range between 14.2 °C and 20.6 °C, respectively, which reflects the humid and temperate nature of the climate in the study area (EMI, 2022; Mengistu et al., 2021). This climatic condition makes the area suitable for diverse crops but also exposes households to variability in rainfall distribution, affecting food security.

As part of the Ethiopian highlands, this area is densely populated, intensively cultivated, and characterized by land fragmentation, land cover degradation, and overgrazing, with a population density ranging from 167 to 746 people per square kilometer (Abebe et al., 2022; Masha et al., 2024; Masha et al., 2021).

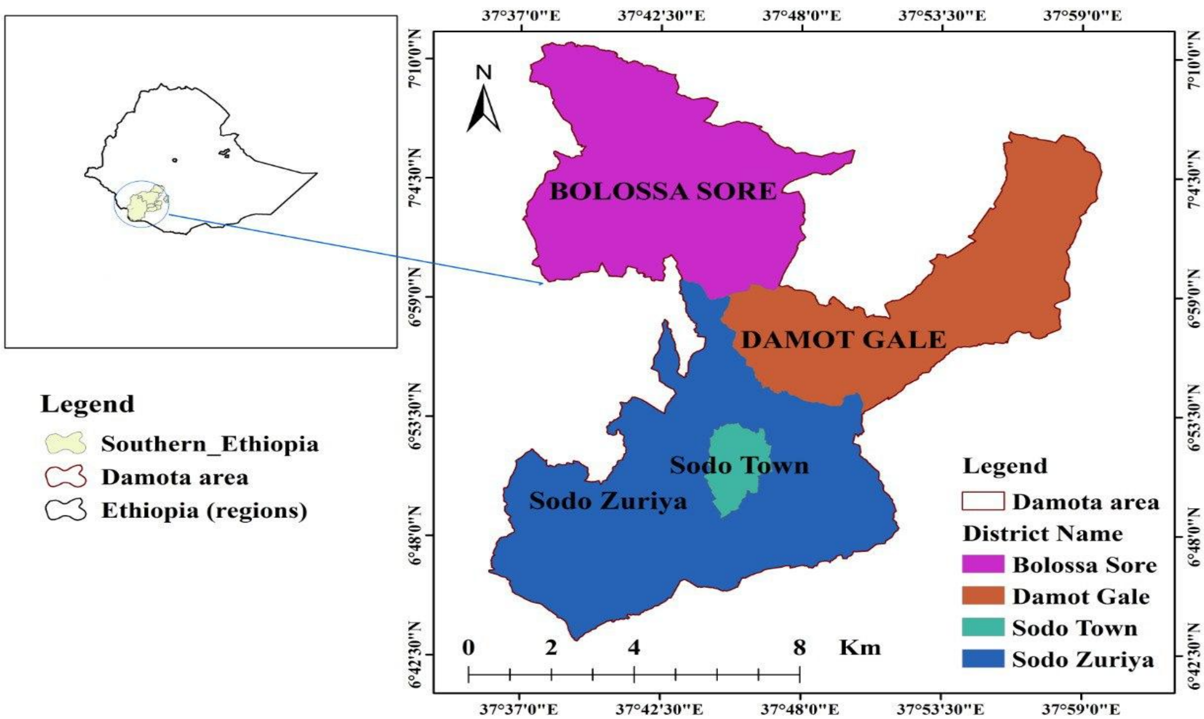

Figure 1. Geographical location of the study

2.1. Research design and approach

In this study, a cross-sectional survey design was used to assess the role of small-scale irrigation practices on food security and determining factors hindering farmers' large-scale adoption.

2.2. Sampling design and sample size determination

Following a multistage procedure of sampling, the study area is purposively selected because the area is identified as one of the irrigation potential and drought-induced food insecure sites in the Wolita Zone. In this regard, households in each rural kebele were stratified into two strata, namely irrigation users and non-users. The total population of the study area kebeles consists of 1170 households. From these, 399 were irrigation adopters and 781 were irrigation non-adopter households. From the total population in the three kebeles (1170 households), 130 households by using the Kothari (2004) formula. Hence, to determine and calculate the sample size, at a 95 % confidence level and ±5 % of precision level was used as the criterion.

$$n = \frac{z^2 * \mathrm{p} * \mathrm{q} * \mathrm{N}}{e^2(N-1) + z^2 * \mathrm{p} * \mathrm{q}} \quad (1)$$

Where, n=sample size, N= population size in this case, which is 1,170, e= accepted error or degree of confidence desired, usually at 0.05, z= standard variation=1.96, p= standard deviation=0.11(11%), q=1, p=0.89.

2.3. Data collection tools

To achieve the objective of the study, the researchers collected data from primary and secondary sources. Trained enumerators who could speak the local language administered a survey with open and closed-ended questions to households from November to March 2023. The three enumerators, who held MSc degrees, were given clear guidance on the questionnaire content and how to elicit reliable responses from the respondents. To further substantiate the study findings, the researchers conducted focus group discussions, structured interviews, and field observations. Three focus groups, each with nine participants, were formed to gather knowledge and experiences on the roles of small-scale irrigation in food security. Structured interviews were carried out with twelve key informants, six local leaders, six selected model farmers, and three development agents to obtain pertinent information on agricultural work and small-scale farming. Field observations were conducted to examine the impacts of irrigation farming on food status and the challenges faced by farmers in adopting such practices.

2.4. Data analys techniques

Qualitative data that were obtained from focus group discussions and field observation, which are subjective and non-numerical, were analyzed through describing, explaining, and interpreting data by using words, pictures, and symbols. The descriptive statistics (frequency, percentage), and inferential statistics were used to analyze the data by using the STATA software package.

2.4.1. Model specifications

2.4.1.1. Household food security measurement: calorie method

The study assessed the food security status of households using the calorie intake method. This approach involves defining a food security line based on a basket of food items typically consumed by households (Scicchitano, 2018). The basket is designed to meet the Ethiopian government's predetermined minimum caloric requirement of 2,200 kcal per person per day, which is aligned with the global food security guidelines. (Gurmu et al., 2019; Fras et al., 2024) This can serve as a basis for developing culturally appropriate food-based dietary guidelines for Ethiopia, where malnutrition remains a significant public health issue. (Gurmu et al., 2019) (Kassie et al., 2023). The total food consumed by households over the last seven days of the survey period was used to estimate the contents of this basket. To determine the caloric intake required for food security, the amount of grain consumed was converted to grams, and the calorie content was estimated using the nutritional profile of commonly consumed foods in the study area (Fikire & Zegeye, 2022).

2.4.1.2. Econometric model: Binary logistic regression

The binary logistic regression model has been applied to identify the major factors that determine farmers' participation in irrigation activities. It was used to estimate dependent dichotomous variables, because these models are appropriate when the decision-making choice is between two alternatives (irrigation workers and non-irrigation workers). Households' involvement in small-scale irrigation work is a dependent variable, which takes a value of zero or one depending on whether or not a household was an irrigator or not (irrigation user=1 and irrigation non-user=0). Thus, the Logistic model is used to identify the determinants of participation in small-scale irrigation work, and to assess factors determining the probability of participation in SSI. The functional form of the logit model is specified as (Gujarati, 1995).

$$Pt=E\,(Y - 1/X) \tag{2}$$

$$\frac{1}{1+e-1b-b1\,x1} \tag{3}$$

For ease of exposition, 1 is written as:

$$P_i = \frac{1}{1+e^{-Z_i}} \tag{4}$$

The probability is expressed by (3), while the probability for a non-participant is:

$$1-P_i = \frac{1}{1+e^{Z_i}} \tag{5}$$

Therefore, we can write:

$$\frac{P_i}{1-P_i} = \frac{1+e^{Z_i}}{1+e^{-Z_i}} = e^{Z_i} \tag{6}$$

Here, (Pi/1-Pi) is simply the odds ratio in favor of the irrigation participant. Finally, taking the natural log of equation (4), we obtain:

$$L_i = \ln\left[\frac{P_i}{1-Pi}\right] = Z_i = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \tag{7}$$

Where Pi is the probability of being for irrigation participants ranges from 0 to 1. Zi is a function of n explanatory variables (x), which is also expressed as:

$$Z_i = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \tag{8}$$

Li is the log of the odds ratio, which is not only linear in Xi but also linear in the parameters. Xi is a vector of relevant household characteristics. If the disturbance term (U) is introduced, the logit model becomes:

$$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + U_i \tag{9}$$

2.4.2. Definition of variables and working hypothesis

The following explanatory variables were hypothesized to influence household food security. In line with previous empirical studies, the explanatory variables were carefully selected and hypothesized to have a potential influence on household food security. These variables were incorporated into the model based on theoretical underpinnings and evidence from related literature.

Table 1. Variable definitions, measurement, and hypothesis

Variable	Type and definition	Measurement	Hypothesis
EDULHH	Dummy, Educational level of head	1=literate, 0= Illiterate	-
SEXHHH	Dummy, Sex of household head	1=Male,0=Female	-
ACCMRk	Dummy, Access to market	1=yes, 0= No	+/-
PESTDIS	Dummy	0= No, 1= Yes	+
REXTCONT	Continuous, Frequency of Extension Contact	Number	-
LIVOWN	Continuous, Livestock	TLU	-
AGEHHH	Continuous, Age of household head	Year	+
FAMISIZE	Continuous, Family size	Number	+
OFF-FAAC	Dummy, Off/non-farm activity	1= participate, 0=Not	-
CULTLAN	Continuous, cultivated land holding size	Hectares	-
CREDACC	Dummy Accesses to credit	0= No, 1= Yes	-

Source: (Masha et al., 2021; Borku et al., 2025)

3. Results

3.1. Perception of the household food security situation of the study area

As presented in Table 2, among the 130 respondents, more than 88.46% strongly disagreed that food was sufficiently available to feed their family members throughout the year. This suggests that the majority of households in the study area experienced inadequate physical food availability. Similarly, approximately 82.31% of the sampled households strongly disagreed with having reliable physical and economic access to food for their families across the year, indicating widespread challenges in both food accessibility and availability. Furthermore, regarding the acceptability of food in terms of being nutritious, safe, and produced in environmentally sustainable ways, about 76.92% of households strongly disagreed, while only around 10% expressed agreement. This highlights that most respondents did not have access to an adequate, healthy, and sustainable diet for their family members throughout the year.

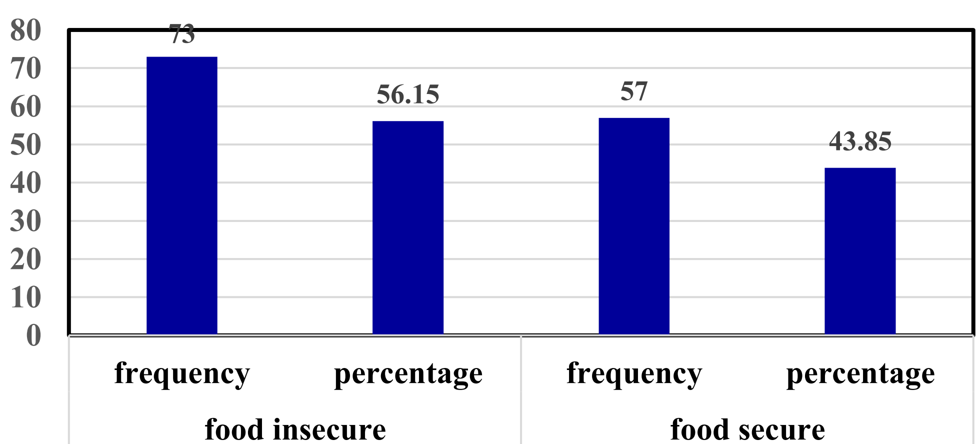

Figure 2. The status of household food security in the study area

Table 2: General food security situation of the sample household

Variables	Categories	Frequency	Percent
There is sufficient food produced on your farmland to adequately feed all family members throughout the year.	Strongly disagree	101	77.69
	Disagree	14	10.77
	Neutral	7	5.38
	Agree	7	5.38
	Strongly agree	1	0.77
Each household members have sufficient physical and economic access to food throughout the entire year.	Strongly disagree	96	73.85
	Disagree	11	8.46
	Neutral	10	7.69
	Agree	8	6.15
	Strongly agree	5	3.85
Each household in your household has access to food that is nutritious, safe, and produced in environmentally sustainable ways throughout the year.	Strongly disagree	100	76.92
	Disagree	13	10.00
	Neutral	8	6.15
	Agree	6	4.62
	Strongly agree	3	2.31
At certain times of the year, all household members face food insecurity as a result of fluctuations in food availability or constraints in food access.	Strongly agree	100	76.92
	Agree	15	11.54
	Neutral	6	4.62
	Disagree	6	4.62
	Strongly disagree	3	2.31
All household members utilize the available food in ways that ensure a healthy and balanced diet.	Strongly disagree	101	77.69
	Disagree	12	9.23s
	Neutral	8	6.15
	Agree	8	6.15
	Strongly agree	1	0.77

Source: Own survey result, 2023.

3.2. The status of food security in the study area

The overall findings in this figure indicate that food insecurity remains a serious concern, with 56.15% of households classified as food insecure compared to 43.85% as food secure. Although the percentage difference between the two groups is about 12%, the fact that more than 43% of households are food insecure underscores the pressing nature of the problem in the study area. On the right side, the figure displays data for food-secure households. Here, 57 households, representing 43.85%, are categorized as food secure. This group signifies households that have relatively stable access to food, ensuring they can meet their dietary needs consistently. These households may have better access to resources such as irrigation systems, income-generating opportunities, or diversified livelihood strategies. The overall findings in this figure highlight a significant gap between food-insecure and food-secure households, with food insecurity being a pressing issue for the majority of the population in the study area.

3.3. Types of available food items produced in the study area

All edible crops produced by households in the study area were gathered to assess their contribution to meeting household food requirements. For comparison purposes, crops from irrigated and rain-fed systems were analyzed separately. The energy content of each crop was converted into household calorie equivalents, allowing a straightforward comparison between irrigation users and non-users. Thus, the results presented in Table 3 effectively corroborate the findings of the 2023 survey.

Table 3. Total grain production distribution

Types of food grains	Total food grain production(quintal)			Food production distribution (%)	
	Rain-fed agriculture	Rain-fed + irrigation agriculture	Total	Rain-fed agriculture	Rain-fed fed irrigation agriculture
Maize (Zea mays)	450.25	681.75	1132	39.7	60.3
Onion Onion (*Allium cepa*)	91	439.125	530.12	17.1	82.9
Tomato (Solanum tuberosum)	35.5	404	439.51	8	92
Potato (Brassica oleracea var. capitata)	195.5	415	610.5	32.1	67.9
Cabbage (Brassica oleracea var. capitata)	87.75	251.125	338.87	25.8	74.2
Teff (Eragrostis tef)	52	22.5	74.50	69.8	30.2
Sweet potato (Ipomoea batatas)	310.25	167.3	477.55	64.9	35.1
Sorghum (Sorghum bicolor)	25	5.5	30.5	81.9	18.1
Haricot bean (Phaseolus vulgaris)	129	62.8	191.8	67.2	32.8
Taro (Colocasia esculenta)	255.4	174.75	430.15	59.4	40.6
Other	120.4	55.12	175.1	68.7	31.3
Total	1631.65	2623.85	4255.5	38.34	61.66
Source: Survey result, 2023					

As can be seen from Table 7, the share of total grain food production was 61.66% (2623.85 quintals) from households combining rain-fed and irrigated farming, compared to 38.34% (1631.65 quintals) from purely rain-fed farming. This shows that farmers engaged in irrigation produced overall larger volumes of food. However, the distribution by crop type reveals variations. Crops such as onion, tomato, potato, and cabbage are highly water-demanding and market-oriented; thus, their production is predominantly supported by irrigation. For example, more than 80% of onion and tomato production came from irrigated systems. In contrast, staple and indigenous crops such as Teff, Sorghum, Sweet potato, Haricot bean, and Taro showed higher proportions under rain-fed farming. This is explained by three main factors: (i) larger land areas are usually allocated for these traditional staples under rain-fed plots, (ii) their planting coincides with the main rainy season, reducing the need for irrigation, and (iii) their cultivation is culturally rooted, and farmers rarely irrigate them compared to vegetables and cash crops. Therefore, while irrigation greatly boosts the production of high-value and water-demanding crops, rain-fed systems still dominate the production of traditional staples in the study area.

3.4. Coping strategies against food insecurity

The survey results indicate that at the initial stage of food deficit, the most common coping strategy was migrating a household member to a nearby town for labor work, with 63.85% (83 households) employing this approach. Nearby towns such as Wolaita Soddo and other local centers provide relatively better opportunities for temporary employment in construction, small-scale trading, transportation services, and other informal activities. Although these jobs are often low-paying and unstable, they generate quick cash income that enables households to purchase food during critical shortages. This reliance on short-term urban labor opportunities highlights the limited rural alternatives and underscores why labor migration remains the primary coping mechanism in the study area. The second most utilized strategy was reliance on social networks through support from relatives, friends, or community members, either as direct donations or small loans, reported by 15.38% (20 households). This finding highlights the role of informal social support systems in cushioning households during food shortages. The third coping strategy involved buying food on credit, adopted by 9.23% (12 households), reflecting the need for financial adjustments during food shortages. Additionally, selling household assets was practiced by 6.15% (11 households), while

borrowing money to buy food accounted for 8.46% (8 households). The least common coping strategy was selling household livestock, reported by only 0.77% (1 household).
At the severe stage of food deficit, households adopted more drastic measures. The most prominent strategy was participation in food-for-work programs, reported by 33.85% (44 households). This reflects the importance of public safety net interventions in addressing food crises. The second major strategy was the sale of livestock beyond normal levels, reported by 28.46% (37 households), signifying a reliance on productive assets to cope with severe food shortages. Additionally, children discontinuing school was reported by 22.31% (29 households), which highlights the long-term impact of food insecurity on education. Food aid was also utilized by 9.23% (12 households), underscoring the role of external assistance in severe stages. Finally, the sale of production equipment was reported by 6.15% (8 households), reflecting a last-resort measure that could undermine future household productivity. In total, the survey data reveal that households employed a variety of strategies at both stages of food deficit, with an increasing reliance on more extreme measures as the severity of the situation worsened.

Table 4. Coping strategy against food insecurity

Rank	Variables	Number	Percent
1st	Migrate a household member to the nearby town for labor work	83	63.85
2nd	Receiving a donation from relatives or friends	15	11.54
3rd	Buy food on a credit basis	12	9.23
4th	Selling household assets	11	6.15
5th	Borrowing money to buy food	8	8.46
6th	Selling household livestock	1	0.77
At a severe stage			
1st	Participate in food for work	44	33.85
2nd	The sale of livestock is more than usual	37	28.46
3rd	Children discontinue from the schools	29	22.31
4th	Food aid	12	9.23
5th	Sale of production equipment	8	6.15
Total		130	100

Source: Own survey results, 2023

3.5 Factors contributing to the adoption of small-scale irrigation for rural food security/insecurity in the study area

The logistic regression (binary) is a statistical method used to examine the relationship between one or more independent variables and a binary dependent variable (i.e., a variable with two outcomes, such as "yes/no" or "participation/non-participation"). In this study, the model was employed to identify factors influencing farmers' participation in irrigation activities as a strategy to enhance rural household food security. The dependent variable is coded as "1" for participation in irrigation activities and "0" for non-participation. The model estimates the likelihood of a household participating in irrigation based on eleven independent predictors. Among these, education level, tropical livestock unit (TLU), market access, family size, and household head age were found to significantly affect household food security. The effects of each independent variable were evaluated using coefficients, standard errors, and odds ratios, which provide information on the direction, significance, and magnitude of the relationships. Prior to applying the logistic regression model, the potential issue of multicollinearity among the independent variables was assessed. For continuous variables, the variance inflation factor (VIF) was used, while contingency coefficients were employed for categorical (dummy) variables. The results indicated no significant multicollinearity among either continuous or categorical variables. Consequently, after screening the hypothesized predictors and verifying the absence of multicollinearity, all selected variables were deemed suitable for inclusion in the logistic regression analysis.

Table 5 Contributing to the Adoption of Small-scale Irrigation for Rural Food Security

Variables	Coef.	Std. Err.	Odds Ratio	Z
Education level of household head	0.089	0.043	1.09	2.07**
Sex of household head	-0.48	0.34	0.613	1.41
Access to Market	1.17	0.15	0.30	2.8***
Pests and disease problems	-0.13	0.48	0.87	0.27
Frequency of extension contact	0.077	0.20	1.08	0.385
Tropical livestock unit (TLU)	0.20	0.10	1.23	2.00**
Age of household head	-0.08	0.03	0.91	2.67***
Family size	-0.44	0.08	0.64	5.5***
Off-farm activities	-0.15	0.41	0.85	0.37
Farm size	-0.039	0.07	0.96	0.56
Access to credit	1.49	2.48	4.45	0.60
_cons	0.60		0.468	1.25
Number of absorptions, 130, LR chi2(14), 29.15, Prob > chi2, 0.0001, Pseudo R2, 0.5113, Log likelihood, -54.423578, Count R2, 0.823				
Source: Own survey results, 2023. Note: *** and ** indicate significance less than 1% and 5% respectively				

Based on findings from Table 5 above, the odds ratio (OR) plays a critical role in interpretation: If OR > 1, the variable increases the likelihood of participation. If OR < 1, the variable decreases the likelihood of participation. Statistical significance is denoted by Z-values, where variables with $p < 0.05$, $p < 0.01$, or more are considered significant. The estimated logit model coefficients, standard error, marginal effect, and their significance levels were presented in Table 4. The log likelihood estimation of 54.423578 and the chi-squared value of 29.15 showed that the likelihood ratio statistics are highly significant ($P < 0.001$) and PR2 0.5113, suggesting the model is a good fit and has a strong explanatory power.

4. Discussion

Based on the results presented in Table 2, the findings highlight significant challenges in food security among the surveyed households. A large proportion of respondents indicated severe issues with food availability throughout the year. Specifically, 77.69% of respondents strongly disagreed with the statement that there is enough food available in their farmland to feed family members consistently. An additional 10.77% disagreed, reinforcing the perception of persistent food shortages. Only 6.15% (including neutral, agree, and strongly agree responses combined) reported any form of sufficiency in food availability. Regarding physical and economic access to food throughout the year, a similarly high percentage (73.85%) strongly disagreed that all family members had access to good food resources, with another 8.46% disagreeing. This result underscores the dual challenge of limited physical access and economic constraints affecting food security. On the other hand, 6.15% (agree and strongly agree combined) believed their families had reasonable access, showing minimal positive responses. The study also assessed whether families have access to nutritious and sustainable food options. Results revealed that 76.92% of respondents strongly disagreed and 6.15% disagreed, indicating that food quality and nutrition remain significant concerns. Only 7.69% of respondents (neutral and agree) believed their families consumed nutritious food produced in sustainable ways. These findings emphasize the alarming reality of food insecurity extending beyond availability to include nutrition and quality. The finding is directly corroborated by other findings (Abera & Mossa, 2020).

In terms of periodic food insecurity, 76.92% of respondents strongly disagreed that their families avoided periods of food scarcity, reinforcing a high prevalence of seasonal food shortages. Another 11.54% disagreed, showing a consistent trend of food vulnerability. Conversely, very few (6.92%) reported neutral or positive perceptions, further highlighting chronic food access limitations. Lastly, the study examined whether family members consume food conducive to a healthy diet. Similar patterns emerged, with 77.69% of respondents strongly disagreeing and 9.23% disagreeing. Only 6.15% agreed that their family consumed healthy food, while 6.15% were neutral. These findings reflect a serious gap in dietary quality, likely due to insufficient access to diverse and nutritious foods (Dula, 2019).

4.1. Food production distribution (rain-fed *Vs* irrigation agriculture)

Ethiopia, as an agrarian economy, relies heavily on agriculture for food production, employment, and economic growth. The country has vast agricultural potential, with diverse agro-ecological zones, fertile land, and abundant water resources. However, food production and distribution face critical challenges, particularly regarding the dependence on rain-fed agriculture and the underutilization of irrigation agriculture. This imbalance has significant implications for food security, particularly in the face of climate variability and population growth (Mohamed, 2016).

The results in Table 7 provide a comprehensive overview of food grain production and its distribution across rain-fed agriculture and irrigation-supported agriculture. The total food grain production for the study area amounted to 4255.5 quintals, of which 38.34% was contributed by rain-fed agriculture, while 61.66% was attributed to combined rain-fed and irrigation agriculture. This finding highlights the critical role of irrigation-supported agriculture in enhancing total production.

The findings supported by Aakash et al. (2022) indicate that maize was the most significant food grain in terms of production in our study, with a total yield of 1132 quintals. Of this, 681.75 quintals were produced through a combination of rain-fed and irrigation agriculture, accounting for 60.3% of the total, while rain-fed agriculture alone contributed 450.25 quintals. This indicates that irrigation plays a major role in boosting maize production, underscoring its importance in addressing food security. Bibe et al. (2017) also support this result. Onion production followed a similar trend, with 82.9% (439.125 quintals) of the total 530.12 quintals produced using irrigation-supported agriculture. Rain-fed agriculture contributed only 91 quintals, highlighting the reliance on irrigation for onion cultivation. This pattern demonstrates that certain crops, such as onions, are particularly dependent on irrigation systems to achieve significant yields. For tomato, total production reached 439.5 quintals, with a striking 92% contribution from irrigation-supported agriculture (404 quintals) and only 8% (35.5 quintals) from rain-fed agriculture. This clearly reflects that tomato farming heavily relies on irrigation, making it less feasible under rain-fed conditions alone. Potato production stood at 610.5 quintals, with 67.9% contributed by irrigation systems (415 quintals) and 32.1% (195.5 quintals) produced under rain-fed agriculture. Similarly, cabbage production totaled 338.87 quintals, where irrigation accounted for 74.2% (251.125 quintals) and rain-fed agriculture contributed only 25.8% (87.75 quintals). These results indicate that root and leafy vegetable crops, such as potatoes and cabbage, also benefit significantly from irrigation to achieve higher productivity. Teff, a staple crop in Ethiopia, showed a reverse trend, with 69.8% (52 quintals) of its total production (74.5 quintals) coming from rain-fed agriculture and only 30.2% (22.5 quintals) from irrigation-supported agriculture. This suggests that teff remains predominantly a rain-fed crop in the study area, unlike many other food grains that rely on irrigation for higher yields. In line with this, Tsegay et al. (2014) suggest that optimal timing for sowing and one-time irrigation during the water-sensitive flowering stage can improve the productivity of rain-fed teff, even with limited irrigation capacity. Sweet potato and taro production showed a moderate dependence on irrigation systems. Sweet potato totaled 477.55 quintals, with 35.1% (167.3 quintals) coming from irrigation agriculture and the remaining 64.9% (310.25 quintals) from rain-fed agriculture.

Similarly, the result from Table 7 revealed taro production reached 430.15 quintals, where rain-fed agriculture contributed 59.4% (255.4 quintals) and irrigation-supported systems contributed 40.6% (174.75 quintals). This indicates that while these crops benefit from rain-fed agriculture, irrigation still plays a complementary role in enhancing overall production. Sorghum had the smallest production volume, with only 30.5 quintals produced. Rain-fed agriculture accounted for 81.9% (25 quintals), while irrigation contributed a minimal 18.1% (5.5 quintals). This highlights sorghum's reliance on rain-fed systems. For haricot bean, total production amounted to 191.8 quintals, where 67.2% (129 quintals) came from rain-fed agriculture and 32.8% (62.8 quintals) from irrigation. Similarly, other crops contributed 175.1 quintals, with rain-fed agriculture contributing 68.7% (120.4 quintals) and irrigation systems contributing 31.3% (55.12 quintals). These results show that leguminous crops and other food grains are still primarily rain-fed, though irrigation has some influence on production. Overall, the findings indicate that irrigation-supported agriculture plays a significant role in increasing food grain production, particularly for crops such as onions, tomatoes, potatoes, and cabbage. In contrast, traditional rain-fed agriculture remains dominant for staple crops like teff, sorghum, and haricot beans. The data underscores and the existing research finding suggests the importance of expanding irrigation infrastructure to enhance agricultural productivity, diversify crop production, and ultimately improve food security in the study area (Bird, 2014; Pandya, 2018). In light of the summarized model results in Table 5, possible explanations for each significant independent variable are given as follows:

Education Level

The coefficient for education level is 0.089, with a standard error of 0.043 and an odds ratio of 1.09. This indicates that for each additional year of education, the odds of participating in irrigation activities increase by approximately 9%. The Z-value of 2.07 confirms this result is statistically significant at the 5% level. This finding is consistent with other studies that highlight the importance of education in promoting agricultural innovation and participation in irrigation schemes. Educated farmers are often more aware of modern agricultural practices and technologies, enabling them to make informed decisions about adopting irrigation methods (Akinyemi, 2012). Research has shown that education enhances problem-solving skills and resource management capabilities, which are essential for effectively utilizing irrigation systems (Porter et al., 2020).

Tropical Livestock Unit (TLU)

The TLU coefficient is 0.20, with a standard error of 0.10 and an odds ratio of 1.23, suggesting that an increase in livestock ownership positively influences participation in irrigation activities by about 23%. The Z-value of 2.00 indicates this result is statistically significant at the 5% level. This finding aligns with the literature, as Zhang & Schroder (2014) indicated that livestock can provide essential resources for farming, such as manure for fertilization and labor for land preparation. Additionally, households with more livestock may have better access to financial resources through livestock sales, which can be reinvested into irrigation infrastructure or technology (Bjornlund et al., 2018).

Access to market

The coefficient for access to market/town is 1.17, with an odds ratio of 0.30, indicating that increased access to markets correlates with a decreased likelihood (by about 70%) of participating in irrigation activities. This result raises questions about market dynamics; it may suggest that while access exists, barriers such as market inefficiencies or lack of demand for irrigated produce hinder effective participation. Research by Magesa et al. (2015), Mango et al. (2018), and Dube (2020) emphasize that access to markets alone does not guarantee effective agricultural engagement; factors like market infrastructure and support services are crucial for translating access into active participation.

Family Size

Family size has a coefficient of -0.44 and an odds ratio of 0.64, indicating that larger family sizes are associated with a 36% decrease in the likelihood of participating in irrigation activities, supported by a Z-value of 5.5 that shows strong statistical significance. This could suggest that larger families may face challenges related to resource allocation or labor distribution that hinder their ability to engage effectively in irrigation practices. Studies have shown that larger households may prioritize immediate subsistence needs over long-term investments like irrigation, reflecting a potential trade-off between family size and resource management capabilities (Gupta et al., 2021).

Age

The age coefficient is -0.08 with an odds ratio of 0.91, indicating a slight decrease (9%) in the likelihood of participation as household heads age further, supported by a Z-value of 2.67 showing statistical significance at the 5% level. This finding suggests that older farmers may be less inclined or able to adopt new agricultural practices compared to younger farmers who might be more open to innovation and change. Other research has indicated generational differences in attitudes toward technology adoption in agriculture, highlighting the need for targeted educational programs aimed at older farmers to enhance their engagement in modern farming practices (Fox et al., 2021; Kumari et al., 2018). In summary, your analysis identifies several critical factors influencing farmers' participation in irrigation activities: education level and TLU positively correlate with participation, while family size and age negatively affect it. The unexpected relationship between access to markets and participation underscores the necessity for further research into barriers limiting effective utilization despite availability. These findings highlight the importance of tailored interventions aimed at enhancing educational opportunities and addressing socio-economic challenges to improve food security through increased irrigation participation among rural households in the study area. By understanding these dynamics, policymakers can develop targeted strategies to promote sustainable agricultural practices and enhance food security outcomes in the region.

5. Conclusion

Food security, at the individual, household, national, regional, and global levels, is achieved when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The objective of this study was to focus on ensuring food security through irrigation farming and its adoption determinants in the Damota area of southern Ethiopia. In contrast, the household's food energy acquisition is higher for those with irrigated agriculture compared to rain-fed dependent households. This high variation suggests that small-scale irrigation is a viable solution to secure household food needs in the study area, and promoting smallholder production of directly consumable food grains is advantageous. The findings indicate that irrigation user households were more food secure than non-users in the study area. The results show a significant calorie difference between irrigation users and non-users, and the higher amount of food sources by irrigation user households is not due to chance, but rather the marginal differences in food crops cultivated from irrigated agriculture. The study results also revealed the determinants influencing the adoption of small-scale irrigation for sustainable food security, which are influenced by the distinctive socio-economic and biophysical features of the sampled households. Households with relatively large cultivable land, education, access to credit, irrigation land, and participation in non-farming activities are more likely to adopt small-scale irrigation farming as a livelihood strategy.

In conclusion, the study area has good potential resources for intensive agriculture, such as irrigation water, land, and labor. The logistic regression results indicate that education level, cultivated land size, access to irrigation, health status, non-farm activity, access to credit service, and using fertilizer positively and significantly influence the adoption of small-scale irrigation farming for sustainable food security. However, the age of the household head negatively affects the adoption of small-scale irrigation farming.

5.1. Recommendation

This study provides important implications for improving household food security and enhancing the productivity of small-scale irrigation farming systems. The following actions are recommended:

- *Promote farmer education and training:* Strengthen adult education, agricultural training, and awareness programs to improve decision-making and adoption of modern farming practices.

- *Improve market access and infrastructure:* Invest in transportation, storage, and market linkages to enable farmers to sell irrigated produce efficiently.
- *Support vulnerable households:* Introduce labor-saving technologies and youth engagement programs to assist aging farmers and larger households.
- *Expand irrigation adoption:* Encourage wider participation in small-scale irrigation, as it reduces poverty, raises crop productivity and income, and improves food security.
- *Strengthen national irrigation strategies:* Government and development partners should scale up both small- and large-scale irrigation schemes to boost rural incomes and resilience.
- *Integrate irrigation in food security programs:* Food security interventions should prioritize irrigation as a key driver of sustainable agricultural production.
- *Encourage multi-dimensional food security assessments*: Use combined indices such as HFIAS, FCS, and DDS for a comprehensive understanding of food security.

5.2. Limitations:

This study was based on cross-sectional data from 130 households in the study area, which limits its generalizability. Future research should incorporate panel data, larger samples, with additional variables and additional indices to capture long-term dynamics and regional variations.

Author' Contributions

Abraham Woru Borku: conceptualized, reviewed, edited & prepared for publication.
Mamush Masha: conceptualized and designed the study, collected relevant data and analyzed the data, and wrote the manuscript.

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