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Improve water productivity and yield through participatory approaches in small-scale irrigation schemes: A case of Shimburit irrigation schemes, Ethiopia

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***Abstract*—Small-scale irrigation schemes in Ethiopia are pivotal for improving agricultural productivity and food security. However, poor water management, infrastructural maintenance, and agronomic practices hinder the potential of the scheme. This study evaluates the Shimburit small-scale irrigation scheme in Ethiopia, focusing on water and crop productivity. Data were collected through surveys, interviews, and field demonstrations of full-package treatments (advanced water and crop management) with conventional farmer practices. Three representative locations were selected from local farmers, considered as replications and wheat was used as a test crop. The results revealed that current irrigated areas were reduced by 25 % of the initially designed capacity. Poor water management practices, seepage and inadequate maintenance were identified as major issues. Adoption of improved irrigation technologies (full-package) treatment gave 3.97 tons ha-1 of grain yield and 0.94 kg m-3 of water productivity. This reveals that advanced water and crop management practices improve wheat yield by 60.7 % and water productivity by 70.9 % as compared to conventional practice. Therefore, advanced water and crop management is essential for enhancing yield and water productivity that supports Ethiopia's agricultural development goals.**

Keywords—Advanced Management, Conventional Practice, Small Scale Irrigation, Water Productivity, Wheat

I. INTRODUCTION

Farmers in Africa face unpredictable rainfall patterns and frequent droughts, leading to low crop yields and income. This is particularly true in Ethiopia, where agriculture relies heavily on rainfall, and most regions have only one growing season [1]. To address this, irrigated agriculture is essential for sustainable food security. Effective water resource management, irrigation development, and advanced irrigation technologies can significantly boost agricultural production and social welfare. Strategies such as river diversions, micro-dams, and water harvesting structures have shown promise in expanding irrigation [2, 3, 4]. Ethiopia has substantial water resources, offering significant potential for water-led development. Most irrigation in the country is small-scale, community-managed, and covers less than 200 hectares [5, 6]. Developing small-scale irrigation has become a policy priority to help Ethiopia achieve middle-income status [7, 8]. However, despite government efforts to build new schemes, many existing ones are poorly managed or non-functional [9, 10]. Improving irrigation efficiency is critical to addressing this issue, enabling more crops to be grown with less water [11]. Irrigation performance, defined as the achievement of desired objectives and a key to evaluating efficiency [12, 13]. Systematic monitoring and assessment of irrigation schemes are essential to meet their goals [14].

Ethiopia's irrigation potential is estimated at 5.7 million hectares, yet only about 3.7 million hectares are currently utilised [15, 1]. With constraints such as technology, funding, and resource availability, the realistic potential is around 2.67 million hectares. Expanding irrigation is vital for improving food security and economic growth. However, while the government focuses on building new schemes, there is insufficient emphasis on monitoring and evaluating existing ones, leading to underperformance [16]. Farmers manage water in small irrigation schemes without the necessary technical expertise, resulting in inefficiencies. Poor design, construction, operation, and maintenance, along with inadequate water control and labor shortages, further hinder performance [12, 17]. Small-scale schemes, which account for 90% of the irrigation performance gap, are particularly affected [18]. In the Amhara region, inefficient water management, poor maintenance, and input supply challenges have significantly reduced the potential benefits of irrigation in small-scale schemes [17, 19]. Inefficient water use at both farm and scheme levels has reduced irrigated land and agricultural productivity. Assessing the performance of existing schemes is crucial to optimising water productivity and enhancing food security. In the Shimburit small-scale irrigation scheme, farmers used their indigenous knowledge to cultivate crops under irrigation, resulting in poor productivity of yield and water allocation. Demonstrating improved irrigation practices through participatory approaches can help sustain these schemes. Therefore, this study aims to assess the perception of farmers and demonstrate improved irrigation management practices at the Shimburit small-scale irrigation scheme, Northwest of Amhara, Ethiopia.

II. Materials and Methods

A. Description of the Study Area

The study was conducted at the Shimburit small-scale irrigation scheme, which is located at 10° 23’ Latitude, 37° 22’ Longitude, and 2046 m.a.s.l at Debre Elias district, Amhara Region, Ethiopia (Figure 1). The water storage structure of this small-scale irrigation scheme is an earthen dam. The scheme was constructed through the Agricultural Growth Program (AGP) fund. The diverted water is being utilised not only for irrigation but also for livestock, household consumption, and fish production in the reservoir. Furrow and flood irrigation methods are the dominant irrigation methods commonly practiced in the scheme (Table I). This scheme is intentionally designed and developed to play a crucial role in the economic, social, improving the standard of living, and environmental landscape within local communities.

TABLE I. Salient Features Of The Schemes

Key features		
Year of construction		2015
Initially irrigated area (ha)		273
Beneficiaries	Male	171
	Female	12
	Total	183
Source of water		River
Major irrigated crops		Wheat, maize, potato, onion, cabbage

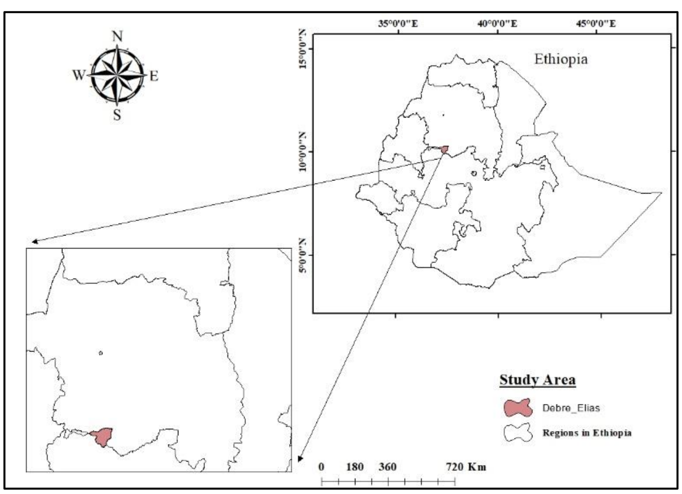

Fig. 1. Description map of the study area

B. Maintaining the Integrity of the Specifications

In this study, a mixed-method approach was employed, incorporating qualitative and quantitative data collection procedures. A cross-sectional survey design was used to collect primary quantitative data. The respondents comprised irrigation beneficiary households (HHs) in the schemes. The sample size (n) for the study was determined using (Eq. 1), adapted from [20].

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

Where: N is the number of populations under study, while ‘e’ is the margin of error, set at the confidence interval of 95 %. This margin of error determines the level of precision desired in the sample results relative to the total population.

1) Qualitative and Quantitative Data Collection

The baseline survey was conducted during the irrigation season. A purposive sampling method was employed to select representative locations and households in the scheme. Additionally, interviews were conducted with members of the irrigation water user associations (IWUAs) and development agents. For the formal data collection, 66 respondents were selected for the interview. Open and closed-ended questionnaires were prepared to gather data from randomly selected households. The questionnaire covered a wide range of topics, including the socioeconomic characteristics of the HHs, the perceptions of HHs about the scheme, the current status of the irrigation system, and various aspects of irrigation water management practices in the scheme. The study collected qualitative data using key informant interviews, focus group discussions (FGD), and field observation. Key informant interviews (KII) including woreda agricultural office experts, kebele extension workers, irrigation researchers, and elder farmers were interviewed using a semi-structured questionnaire. FGDs were conducted to gain deeper insights into the performance of irrigation schemes, technology demonstration, and related issues. The FGD participants were diverse, including farmers with different wealth statuses, genders, and ages, with each group consisting of 8-12 members. The group discussions were facilitated using a semi-structured checklist to ensure comprehensive coverage of relevant topics.

2) Estimation of the irrigation scheme's sustainability

The productivity of irrigation schemes can be estimated by the ratio of the currently irrigated area to the initially irrigated area at the time of design [21, 22] as given in (Eq. 2) below. This sustainability ratio serves as a crucial indicator for assessing the sustainability of irrigated agriculture. The lower values of this indicator suggest that lands that were initially irrigated are being abandoned, indicating a contraction of irrigated areas over time. Conversely, values higher than one indicate the expansion of irrigated areas, implying more sustainable irrigation practices [23]. The results of this study indicated that the status of all the schemes was below their sustainability threshold.

$$Sustainability\ Ration = \frac{\text{Current Irrigated area (ha)}}{\text{Initially Irrigated area (ha)}} \quad \text{.....(Eq.2)}$$

3) Crop and Irrigation Water Requirements

CROPWAT 8.0 model was used to determine the crop water requirement and irrigation water requirement of wheat. Climate data spanning ten years (2011 – 2021) were sourced from nearby meteorological stations, using the nearest neighbourhood to ensure accuracy. Crop-specific data such as root depth, crop coefficient, critical depletion, yield response factor, and length of plant growth stage were derived from FAO irrigation and drainage paper 56 [24]. The planting date under irrigation in the study area started in mid-November. Soil properties including field capacity (FC), permanent wilting point (PWP), infiltration rate, and initial soil moisture depletion, were determined using the gravimetric method. The FAO Penman-Monteith method was used to estimate reference evapotranspiration (ETo), crop evapotranspiration (ETc), and irrigation water requirement (IWR), as specified in (Eq. 3), (Eq. 4), and (Eq. 5), respectively. Additionally, the United States Department of Agriculture (USDA) Soil Conservation Service method [25] was used to estimate effective rainfall.

$$ETo = \frac{0.408\Delta(\mathrm{Rn}-\mathrm{G})+\gamma\frac{900}{\mathrm{T}+273}\mathrm{U2}(\mathrm{es}-\mathrm{ea})}{\Delta+\gamma(1+0.34\mathrm{U2})} \quad \text{(Eq.3)}$$

$$ETc = ETo \; x \; Kc \quad \text{(Eq.4)}$$

$$IRn = ETc - (Pe + Ge + Ws) + LR \quad \text{(Eq.5)}$$

Where: ETo = reference evapotranspiration [mm day-1], Rn = net radiation at the crop surface [MJ m-2 day-1], G = soil heat flux density [MJ m-2 day-1], T = mean daily air temperature [°C], U2 = wind speed at 2 m height [m s-1], es = saturation vapor pressure [kPa], ea = actual vapor pressure [kPa], es-ea = saturation vapor pressure deficit [kPa], Δ = slope vapor pressure curve [kPa °C-1], γ = psychrometric constant [kPa °C-1], ETc = Crop Evapotranspiration (mm day-1), Kc = Crop coefficient, IRn = Net irrigation requirement (mm), Pe = Effective rainfall (mm), Ge = Groundwater contribution from water table (mm), Ws = Water stored in the soil at the beginning of each period (mm) and LR = Leaching requirement (mm).

C. Treatment Design

The appropriate sites and host farmers for technological trials were selected jointly with development agents (DAs) and woreda agriculture offices. Accordingly, a total of 3 farmers were selected based on their willingness and the suitability of their lands, and participated in experimenting on their farmlands. The three farm plots were planted with wheat crops, and each farmer was considered a replicate. Each demonstration plot was 10 m by 10 m, strategically positioned at the head, middle, and lower sections of the irrigation schemes. The experiment treatments were as shown in Table II:

1) Improved irrigation technology (Recommended full package): a wheat variety of Kekeba was used with a spacing of 20 cm between rows, 40 cm furrow width and 80 cm bed width by drilling seeds using a seed rate of 150 kg ha-1 was applied. In addition, a recommended fertiliser rate of 244 kg ha-1 NPS (blended Nitrogen, phosphate and sulphur at planting, 254 kg ha-1 Urea (half at planting and the rest half at 45 days after planting) and 4223.4 mm mm3 ha-1 depth of crop water requirement (CWR) within 14 days was applied. The volume of water applied was accurately measured using a Parshall flume in the growing season.
2) Farmers' conventional practice with recommended CWR: in this treatment, only the recommended depth of water was applied, while other practices (fertiliser, spacing, variety, and other agronomic practices) were considered farmers' practices.
3) Farmers' conventional practice: all activities are monitored by farmers, and important data are collected.

TABLE II. TREATMENT DESIGN

Treatment	Variety	Spacing (cm)	Seed rate (kg ha^{-1})	Fertilizer (kg ha^{-1})	
				NPS	Urea
1	Kekeba	20, 40, 80	150	244	254
2	Kekeba	20, 40	200	350	400
3	Kekeba	20, 40	200	350	400

D. Data Analysis

Data analysis involved various methods to handle both qualitative and quantitative information. Techniques such as content analysis and descriptive statistics were used, along with stakeholder analysis. The quantitative data were processed using SPSS version 22, while STATA version 14.1 was used for statistical analysis.

III. RESULTS AND DISCUSSIONS

A. Socio-economic Characteristics

The socio-economic characteristics of the sample households were documented, and the analysis included interviews with 66 households, of which 64 were male-headed households and 2 were female-headed households. This finding highlights a significant gender disparity in participation rate within irrigated agriculture, with male-headed households predominantly more involved than female-headed counterparts. This pattern of low female participation mirrors findings [26, 27, 28, 29], which reported lower involvement of women compared to male farmers in irrigated agriculture. Households in these irrigation schemes have a broad range of experience in irrigated agriculture, with a mean duration of 9.28 years (Table III). Initially, the farmers had predominantly relied on traditional irrigation before the introduction of modern irrigation infrastructure. Despite the introduction of modern techniques, the size of farmland remained consistent for both main and irrigated seasons in the schemes (Table III), with an average land size was 0.69 ha.

TABLE III. IRRIGATION EXPERIENCE (YEARS) AND FARM SIZE

Variables	Observation (N = 66)	
	Mean	Stdev
Irrigation experience (yr)	9.28	8.23
Total farmland size (ha)	1.60	1.38
Irrigated (ha)	0.69	0.50

Note: N = number of observations, Stdev = Standard Deviation

B. Farmers' Perception of the Irrigation Scheme

The result of the perception rate of the respondents showed that only 13.6 % expressed their dissatisfaction primarily due to incomplete canal structures, particularly inadequately lined canals and the lack of proper maintenance (Table IV). Specifically, 54 % of respondents were satisfied with canal structure systems. The outcome was validated through a comprehensive analysis involving focus group discussions (FGD), field observation, and key informant interviews as discussed in the following section.

TABLE IV. FARMER'S PERCEPTION

Variable	Frequency	Percentage
1. Satisfaction layout of irrigation		
No	9	13.6
Yes	57	86.3
2. Why not satisfied		
Poor alignment of canal structure	4	44.4
Poor setting of off takes	4	44.4
Lack of other facilities	1	11.1
3. Satisfaction with canal and structure		
No	30	45.4
Yes	36	54.5
4. Why not satisfied with canal structure		
Poor construction	3	10.3
Incompleteness	15	51.7
Poor operation	5	17.2
Poor maintenance	7	20.6

C. The Status of the Irrigation Scheme

Field observation and expert insights highlighted that seepage and overtopping of canal flows were significant challenges affecting the proper functioning of the irrigation systems in the study area. These issues primarily stem from inadequate monitoring and the lack of regular maintenance, as documented by [30, 12]. A common feature assessed in the schemes was long canals constructed over steep topography. Seepage is identified as the predominant issue in the Shimburit scheme (Table V). Household interviews further confirm that poor construction (incompleteness of the canal structure) and insufficient maintenance were the primary causes of the ongoing seepage issues. This result reveals that a detailed investigation is required to gather good information on the seepage analysis in the study area.

TABLE V. PROBLEMS AT SHIMBURIT IRRIGATION SCHEME

Questions	Frequency	%
1. Is there a Seepage/leakage problem?		
A. No	29	44
B. Yes	37	56
2. What is the reason for seepage ?		
A. Poor construction	15	41
B. Lack of Mainctenance	17	46
C. Both	5	14

D. Some Common Mistakes

Table VI presents the results of the sustainability ratio for the Shimburit irrigation scheme was 0.75, which is below 1. These figures indicate a notable decline in the irrigated areas, with reductions of 25 % from the originally irrigated areas, respectively, aligning with the findings from prior research by [31]. In contrast, other studies, such as the Golgota irrigation scheme, reported a sustainability ratio of 1.2 [23], and the Werka scheme exhibited a ratio of 1.46 [32]. Interestingly, sustainability ratios exceeding 1 in these cases suggest the potential for expanding irrigated areas, provided there is a dependable irrigation water supply meeting crop water demands. The current analysis highlights that this scheme falls below the threshold of the sustainability ratio, emphasising the urgent need for further improvements in its management and operational efficiency. Similar research highlighted that numerous irrigation schemes across various regions of Ethiopia are not functioning up to their intended capacity, primarily due to a combination of factors such as design inadequacies, poor water and agronomic management practices, limited support from local institutions, and the exacerbating issue of excessive siltation [9]. These challenges collectively impede the effective operation and productivity of the irrigation systems, leading to suboptimal outcomes for the stakeholders involved. Furthermore, water management issues pose significant obstacles for small-scale irrigation projects in Sub-Saharan Africa, which eventually result in high levels of unsustainability [33].

TABLE VI. IRRIGATION POTENTIAL OF THE SCHEMES

Area	Value
Designed irrigation area (ha)	273
Current irrigation area (ha)	207
The sustainability ratio of the scheme	0.75

E. Management and Practice of Irrigation Water

Management practices in the schemes involve collaborative decision-making processes between users, the development agent (DA) and the water user association. In the study area, wheat, maize, potato, onion, and cabbage were dominantly cultivated by farmers. However, this cropping pattern was dominantly affected by the local market price of the crop, which made a 53.03 % contribution than seed supply and farmers' preference (Table VII). When there was a water shortage and drought problems in the scheme, farmers extended the irrigation interval as an option to cultivate crops. The irrigation intervals and duration of irrigation water were mostly determined by the irrigation water user association (IWUA), and most farmers irrigate wheat on average 15 to 18 days irrigation interval without quantification of crop and irrigation water requirements. IWUA and DA gave priority consideration for female (71.49 %) farmers in irrigation water duration and seed supply, as compared to male farmers, to encourage female participation in the scheme. The interview and survey data showed that farmers in the Shimburit irrigation scheme dominantly (95.45 %) used the furrow irrigation method, and the length of the furrow was determined by the type of soil and the slope of the land. The baseline survey revealed that the irrigators of this scheme predominantly utilise furrow irrigation techniques. Therefore, capacity building is required for the proper application of furrow irrigation techniques.

TABLE VII. IRRIGATION PRACTICE AND MANAGEMENT

Variable	Frequency	Percentage
1. Factors for developing a cropping pattern		
Supply	23	34.85
Market	35	53.03
Preference	6	9.09
Other	2	3.03
2. Measurement during water shortage		
Reduce area	22	33.33
Extend irrigation interval	34	51.52
Cover more land with less watering crop	4	6.06
Other	6	9.09
3. Who determine irrigation interval		
DA	19	28.79
IWUA	34	51.52
Household	13	19.70
4. Who is fixing irrigation duration		
DA	8	12.12
IWUA	44	66.67
Household	14	21.21
5. Who receive the priority		
Male	1	14.29
Female	5	71.49
Disable	1	14.23
6. Method of irrigation practice		
Furrow	63	95.45
Flooding	2	3.03
Basin	1	1.52
7. Do you consider the length of the furrow by slope and soil type		
No	4	6.06
Yes	62	93.94

F. *Yield and Water Productivity of Wheat*

Demonstration of on-farm crop and water management technologies was conducted after the baseline survey. The result showed that it has significantly impacted the grain yield and water productivity of wheat in the scheme. The mean comparison test results confirmed that there was a statistical difference ($p < 0.05$) in grain yield between the recommended full package (3.97 ton ha-1) and farmer practice (2.47 ton ha-1), however, there is no statistical difference between recommended full package and farmers practice with recommended crop water requirement (3.05 ton ha-1) treatments (Table VIII). This result indicated that the amount of water applied has a great impact on grain yield. The wheat yield obtained from the full package aligns closely with the global average wheat yield in 2020, which was reported as 3.45 ton ha-1 by [34] and a productivity level of 4 ton ha-1 in Ethiopia [1]. The application of the full package led to a remarkable 38 % increase in grain yield compared to the conventional farmer's practice, which is currently used by farmers in the scheme (Table VIII). This difference was further highlighted by the water productivity, with the full package treatment outperforming at 0.94 kg m-3 as contrasted to the 0.55 kg m-3 achieved with the farmer practice.

This study revealed that the recommended full package has a 267.5 m3 ha-1 (6.3 %) saved applied water and 28.8 % water productivity advantage as compared to the conventional irrigation practice. This showed that the saved water can be utilised to cultivate an additional 0.1 ha of extra land or can produce a grain yield of 251.5 kg ha-1 wheat (Table IX). This revealed that the saved water can produce a small amount of yield, even though it has a 28 % yield advantage. This indicated that water is not the only factor in the full package. Since farmers used a series of furrows (spacing 20 cm between rows and 40 cm furrow width) may cause loss of productive land for furrowing purposes as compared to the recommended (20, 40 and 80 cm; between row, furrow width and bed width respectively) irrigation practice, in addition to seed and fertiliser rate recommendations. The findings of this study align with previous research indicating the advantages of bed irrigation practice. For instance, in Egypt, [35] reported that the bed irrigation method has 32 % and [36] 25 to 28 % yield advantage in wheat cultivation as compared to traditional irrigation practice. Therefore, it is strongly recommended that farmers adopt the full package to enhance the yield and water productivity of wheat in the study area.

TABLE VIII. APPLIED WATER, YIELD AND WATER PRODUCTIVITY OF WHEAT

Treatments	Mean AW (m^3 ha^{-1})	Mean GY (ton ha^{-1})	Mean WP (Kg m^{-3})
CP	4490.9	2.47^b	0.55^c
CP + RCWR	4223.4	3.05^{ab}	0.73^b
RFP	4223.4	3.97^a	0.94^a
CV (%)	2.6	23.2	23.3

Note: CP = Conventional Practice, RCWR = Recommended Crop Water Requirement, RFP = Recommended Full Package, GY = Grain Yield, AW = Applied Water, WP = Water Productivity, CV = Coefficient Of Variation.

TABLE IX. RELATIVE ADVANTAGE OF FULL PACKAGE ON AW, GY AND WP

Treatment	AW Saved	Yield Advantage	WP Advantage	Additional Land	Additional Yield
	%	%	%	(ha)	(Kg ha^{-1})
CP	-	-	-	-	-
CP + RCWR	**6.3**	**24.8**	**32.7**	**0.1**	**195.3**
Full Package	**6.3**	**60.7**	**70.9**	**0.1**	**251.5**

Note: CP = Conventional practice, RCWR = Recommended crop water requirement, RFP = Recommended full package, GY = Grain yield, AW = Applied water, WP = Water productivity,

IV. CONCLUSIONS AND RECOMMENDATIONS

This study evaluated the performance of the Shimburit small-scale irrigation scheme in Ethiopia's Amhara region, identifying key socio-economic and technical challenges. Key findings reveal that poor infrastructure maintenance and seepage losses have reduced the scheme's irrigated area by 25 % of its designed capacity. Gender disparities persist, with male-headed households dominating participation by 97 %. Adoption of improved practices (full-package treatment) demonstrated yields increased by 60.7 %, and water productivity increased by 70.9 %. These highlighted the synergistic benefits of combining optimised irrigation scheduling, modern agronomy, and farmer training. Therefore, prioritising infrastructure rehabilitation and capacity-building programs for farmers and gender-inclusive policies are essential to improve yield and water resources.

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