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Research Article

Technical Evaluations of Ujummo Irrigation Scheme Performance at Haru, Western Ethiopia

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Abstracts

For a number of reasons, many irrigation projects are underperforming; these need be fixed to raise the programs' productivity and efficiency. The purpose of this study was to evaluate the effectiveness of the Ujummo irrigation scheme in western Ethiopia's West Wolega Zone. The average conveyance efficiency (70.3%), field application efficiency (38.62%), average water storage efficiency (61.1%), irrigation uniformity (90.68%), and overall irrigation efficiency (27.14%) were all measured in the field. But the distribution of water was uniform, maybe because canal portions experienced disproportionate losses. The scheme also had relative water supply of 15.91, relative irrigation supply of 10.89, output per unit command area was 1324.24 ($/ha), its output per unit irrigation supply was 0.103 ($/m^3), its output per unit water consumed was 0.67 ($/m^3), its sustainability of irrigation area was 0.82 and its irritation ratio was 1.34 and this indicate there is expansion of irrigate land without additional any irrigation structures and use only the design capacity of the scheme.

Keywords

Irrigation, Scheme, Project Performance, Overall Efficiency, Small-Scale

1. Introduction

Rain fed agriculture is the primary source of food production in Africa, but its productivity is hindered by moisture stress due to inadequate rainfall and prolonged dry spells. Rapid population growth, climate change, and rainfall variability also affect agricultural practices in Sub-Saharan African (SSA) countries [5, 9, 35].

Irrigation is a sustainable alternative for agricultural production, covering over 40% of global agricultural production. Developed countries dominate this area, while developing countries in SSA have underexploited their irrigation potential. Several SSA countries have developed irrigation policies and strategies to improve smallholder agriculture development, partnering with organizations like the World Bank, International Fund for Agricultural Development, and the African Development Bank [8, 28, 16].

However, implementation often suffers due to inadequate planning, improper study and design, and inferior construction. Water is a finite resource used extensively in various industries, and the growing need for food has created competition for this limited resource. Irrigated agriculture is the most

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water-intensive and inefficient sector worldwide, accounting for over 70% of water extraction from sources such as lakes, streams, and aquifers [32]. Performance evaluations are essential to increase irrigation schemes' production, gauge progress toward strategic objectives, evaluate the overall health of the system, identify bottlenecks, gain a better understanding of performance determinants, and compare performance over time or with other systems [1, 2].

2. Materials and Methods

The study irrigation scheme is located in Haru woreda, West Wollega zone, Oromia National Regional State, Western Ethiopia. The district is situated between the latitude of 8°56'15.63" North and longitude of 35°48'17.19" East at an elevation of 1757 m.a.s.l. The area has a uni-modal rainfall pattern with an average annual rainfall of 1585 mm. The rainy season starts in March or May and extends up to October. The soil type is Acrisols and sandy clay loam. The scheme aims to develop 42.5 ha of the irrigated area at Dogi Adare kebele, with long-term climatic dates presented in a Table 1.

Table 1. *Long term climatic data of study site.*

Month	Min Temp ℃	Max Temp ℃	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day
January	15.6	28.4	74	4	8	19.4
February	16.5	30.2	68	4	8	20.6
March	16.9	31.1	70	5	7	20.1
April	16.7	30.6	45	4	8	21.8
May	15	29.5	80	3	6	18.3
June	13.4	26.7	78	3	4	15
July	12.7	26	90	4	3	13.6
August	13.1	26	89	3	2	12.4
September	13.6	26.5	95	3	5	16.9
October	14.8	27.3	85	4	6	17.8
November	14.7	28.5	78	4	7	18.1
December	16.6	29.4	82	4	8	18.9
Average	15	28.4	78	4	6	17.7

3. Data Collections

During the 2022/23 irrigation season, secondary and primary data were collected, and three fields representing the front, middle, and back of the water user hierarchy were selected to evaluate the irrigation scheme performance system using technical performance indicators. The fields were chosen considering crop growth stage, dominance, and crop cover.

3.1. Soil Texture and Bulk Density

Using a soil auger and core sampler, samples of disturbed and undisturbed soil for textural analysis and bulk density were taken from each scheme at five different locations along the diagonal of the chosen fields (head, middle, and tail end) at depths of 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm. The textural analysis approach employed was the hydrometer method and used the following formula to calculate the bulk density [11].

$$\mathrm{Bd} = \frac{\mathrm{Ws}}{\mathrm{Vt}} \tag{1}$$

Where Bd=bulk density of soil g/cm^3 Ws =oven dry soil weight gm, Vt= volume of core cm^3

3.1.1. Field Capacity and Permanent Wilting Point

To determine the moisture content at field capacity (FC) and permanent wilting point (PWP), soil samples were taken at intervals of 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm from five places along the diagonal of the selected scheme.

The permanent wilting point (PWP) and field capacity (FC) were determined at 1/3 and 15 bars of pressure, respectively, using a pressure plate instrument. Based on the FC, PWP, and root depth data, the volumetric total accessible water (TAW) was calculated using the following formula [6].

$$\mathrm{TAW} = 1000 \sum (\theta \mathrm{Fc} - \theta \mathrm{pwp}) * \mathrm{zd} \qquad (2)$$

Were TAW=Total Available water in root zone mm/m, θFC= moisture content at field capacity m^3/m^3, θPWP= Moisture content at permanent wilting point m^3/m^3 Zd= root depth m.

3.1.2. Soil Moisture Determination

Using the gravimetric approach, determine the soil's moisture content both before and after irrigation. Up to 120 cm, soil samples were taken at intervals of 30 cm. The following formula was used to calculate the soil's water content in the volume base [11].

$$\theta v = Bd * \theta m \qquad (3)$$

Were θv=volumetric moisture content %, Bd =Bulk density g/cm^3

3.1.3. Flow Measurement

The amount of water applied by the irrigators to the field at the head, middle, and tail of an irrigation event was measured using a three-inch Par shall flume. At the straight, uniform entry to the farmers' field of choice, a Par shall flume was erected. The following formula provides the basis for the connection between irrigation water head and discharge [31].

$$Q = C * H^n \qquad (4)$$

Were H water depth measured at one third from inlet of converging cm, C and n constant for flume of three inch throat, Q=Discharge of the flow m^3/s.

$$Q = v \times A \qquad (5)$$

Were v=velocity of water m/s, A=Cross section area m^2, Q in m^3/s.

However, the observed velocity was multiplied by correction factor 0.85 for hard or rocky bottoms and 0.9 for smooth, muddy, sandy, or smooth bedrock situations [7].

3.1.4. Field Layout and Crop Selection

To evaluate the irrigation application, deep percolation ratio, storage and distribution uniformity of farmer's field three farmers' fields was selected from the sample irrigation schemes at the head, middle and tail end water users with respect to the water source. The selection of fields was considered willingness of the farmers to collaborate. The dominant crop, which is most of the schemes land is covered with it, was used as testing crop, accordingly at Ujummo irrigation scheme, maize, paper, potato, tomato and wheat crop were used as testing crop. The amount of water irrigated at head, middle and tail reach was measured.

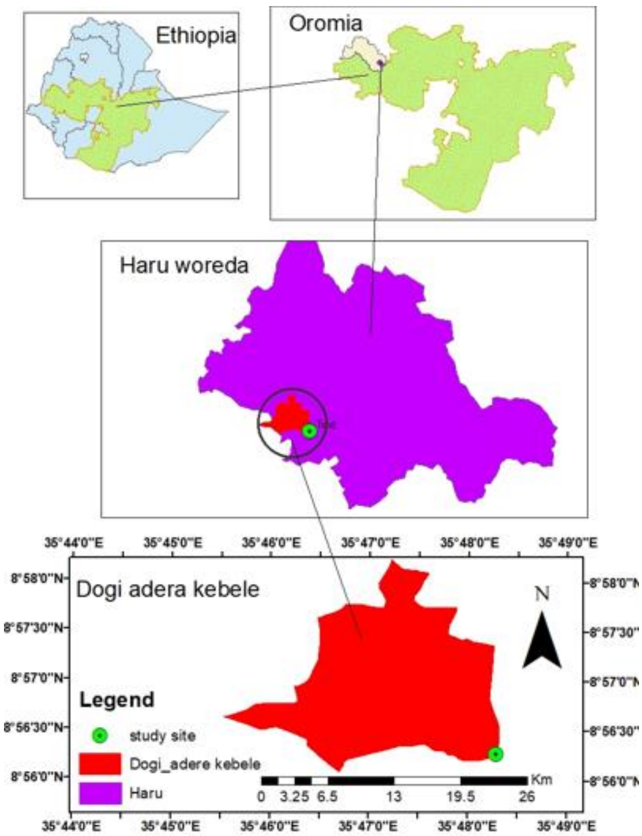

Figure 1. *Study site.*

3.2. Technical Performance Indicators

3.2.1. Internal Indicators

For this project study, five internal performance indicators were used in order to evaluate the internal system performance of the selected scheme, as listed below. Among the internal indicators field conveyance efficiency, application efficiency, storage efficiency, deep percolation ratio and distribution uniformity were evaluated for the selected crop.

3.2.2. Irrigation Efficiency

Irrigation water loss occurs in the conveyance and distribution system, uneven water dispersal, and percolation under the crop root zone. It can also occur due to runoff at the end of channels and border furrows. Efficient planning, design, and operation can minimize losses. Efficiency words include application, uniformity, storage, and adequacy, with supplementary terms like runoff ratio and deep percolation ratio. Distribution, application, and storage efficiency are the main performance metrics [10, 14].

3.2.3. Conveyance Efficiency (Ec)

Water conveyance efficiency (Ec) is a percentage ratio between water supplied to the conveyance system and water conveyed through a channel. It assesses the effectiveness of the water conveyance system in field channels, water courses, and canal networks. Ec is a widely used output measure focusing on the physical water conveyance efficiency of irrigation systems. Water losses in the conveyance system can account for a significant portion of total water losses, especially for farms with distant water sources and unlined main canals. The type of soil and the standard of operation and maintenance also influence water waste and it was computed using the following equation [13].

$$Ec = \frac{\mathrm{Qou}}{\mathrm{Qin}} * 100\% \qquad (6)$$

The overall conveyance efficiency of the schemes was computed using the following equation.

$$Ec{=}Em* \qquad (7)$$

Where:- Ec: conveyance efficiency (%), Em: conveyance efficiency of the main canal (%),

Es: conveyance efficiency of secondary canal (%), Losses in conveyance system was computed as;

$$\mathrm{Lc}{=}Q_{in}{-}Q_{out} \qquad (8)$$

Where: - Lc: conveyance loss (m^3/sec), Q_{in} and Q_{out}: are the inflow and outflow discharge in specified canal length (m^3/sec).

3.2.4. Water Application Efficiency (Ea)

In field supply channels, water application efficiency is critical since it measures the process's efficacy. Water application efficiency below 100% can be attributed to seepage losses, deep percolation, and runoff losses. The amount of water retained in the root zone and at least one of these losses must be ascertained in order to compute application efficiency. Losses and under-irrigation in the soil profile need to be computed. In basin, border, and furrow kinds of systems, achievable application efficiencies for surface irrigation are 80-90%, 70-85%, and 60-75%. It is generally accepted that a minimum of 0.6, or 60%, is adequate, and that the efficiency of water application decreases as the volume of irrigation water applied increases [10].

$$\mathrm{Ws} = \frac{\theta v \times d}{100} \qquad (9)$$

$$\mathrm{Wf} = \frac{Q \times t}{A} \qquad (10)$$

Where Q: discharge of irrigation water applied with respective Parshall flume head (lit/sec);

t: application time (sec); A: irrigated land area within the applied time (m^2). Application efficiency was computed as follows [13].

$$\mathrm{Ea} = \frac{\mathrm{Ws}}{\mathrm{Wf}} * 100\% \qquad (11)$$

Where: - Ea: application efficiency (%); Ws: average depth water stored in the root zone of the plant (mm); Wf: average water delivered to the irrigation field in depth (mm).

Water Storage Efficiency (Es)

Maintaining high water application efficiency from limited irrigation depends on effective water storage. Prior to watering, all necessary water is stored in the root zone. High water storage efficiency is crucial in places where there are few water sources or lengthy water seepage periods. It's also very important to keep the salt balance positive. The level of root zone replenishment attributed to irrigation is indicated by storage efficiency (Es). A clever way to save water in regions with a lot of rainfall is to under irrigate, and this practice has a direct impact on agricultural output. It can be difficult to pinpoint the precise amount of under-irrigation at the farm level, though, Storage efficiency was determined as

$$\mathrm{Es} = \frac{\mathrm{Ws}}{\mathrm{Wn}} * 100\% \qquad (12)$$

Where: - Es: storage efficiency (%); Ws: water stored in the root zone during irrigation (mm), Wn: water needed in the root zone prior to irrigation computed using the following equation [13].

$$Wn = \sum_i^n (\mathrm{Mfci} - \mathrm{Mbi})/100 * \rho b/\rho w * di \qquad (13)$$

Where: - Wn: net amount of water applied during an irrigation (mm); Mfci & Mbi: moisture content at field capacity and before irrigation in the ith layer of the soil (%), respectively; ρb & ρw: bulk density of the soil in the i^{th} layer and density of water (g/cm^3); di: - depth of the soil layer within the root zone (mm); n: - number of soil layers in the root zone.

3.2.5. Water Distribution Efficiency (DU)

Crop yields depend heavily on the field being irrigated by the irrigation flow. At lower levels, over-irrigation happens in clayey soils, while under-irrigation happens in sandy soils. Crop yields are impacted by agronomic variables such as over- and under watering, which can cause plant stress, soil moisture tension, and lower agricultural output. A lack of water can also encourage the growth of plants, make diseases more common, or cause nutrients to be leached.

$$X = \frac{\mathrm{Mai} - \mathrm{Mbi}}{100} * \rho b/ \rho w * di \qquad (14)$$

Where: - X: soil moisture content stored at a particular point (mm); Mai: & Mbi: moisture content of the i^{th} layer of the soil after and before irrigation, respectively on weight basis (%); ρb & ρw: bulk density of the soil in the ith layer and density of water (g/cm^3); di: - depth of the soil in the i^{th} layer (mm).

The total depth of water stored at each point (X1 to X5) was determined, by sum up the values of X1 (0-30), X1 (30-60), X1 (60-90) and X1 (90-120) of that specific point.

That was: X1 = X1 (0-30) + X1 (30-60) + X1 (60-90) to X5 = X5 (0-30) + X5 (30-60) + X5 (60-90) Then finally, the distribution uniformity was determined using the equation below.

$DU = XLq / Xm * 100$ Where:-Du: Water distribution uniformity (%); Lq: the mean of lower-quarter depth of water infiltrated (mm); $X\ m$: the mean depth of all water infiltrated (or caught) (mm).

Project Efficiency (Ep)

This demonstrates how well crop cultivation uses the water source. It displays the portion of the total water that is retained in the soil and made accessible for the crop's consumptive needs. It shows how effective the processes are overall, from head work to the plants' ultimate consumption. To determine the amount of water needed at the diversion head work, the project's overall efficiency must be taken into account.

$$Ep = Ec \times Ea \quad (15)$$

Where: Ep: overall scheme efficiency (%); Ec: conveyance efficiency (%); Ea: application efficiency (%)

Deep Percolation Ratio (DPR).

Deep percolation may result in a serious regional water quality issue, depending on the chemical makeup of the groundwater. The deep percolation ratio represents the amount of water lost by drainage outside of the root zone. The deep percolation ratio was calculated by using the following equation [24, 38].

$$DPR = 100 - Ea - RR \quad (16)$$

Where: - DPR: Deep percolation ratio (%); Ea: application efficiency (%); RR: runoff ratio (%)

3.3. External Indicator

For this performance evaluation, following external indicators was used as illustrated by International Water Management Institute (Molden *et al.*, 1998).

3.3.1. Agricultural Output Indicators

The Haru woreda Agricultural Office provided data for the study in order to calculate external indicators such as output per cropped area, command area, and water consumption. The crop yield production of the chosen irrigation scheme and the local farm gate price were used to compute the total production. Equations were utilized in the study to compute four fundamental comparative measures of agricultural output [1]. It includes four basic comparative indicators listed below:

$$\text{output per unit irrigated area (\$ha)} = \frac{\text{Productioni}}{\text{irrigated cropped area}} \quad (17)$$

$$\text{output per unit irrigated area(\$ha)} = \frac{\text{Production}}{\text{Command area}} \quad (18)$$

$$\text{Output per unit irrigation diverted} \left(\frac{\$}{\text{cubic}}\text{meter} = \frac{production}{irrigation\ diverted}\right) \quad (19)$$

$$\text{Output per unit water consumed(\$/cubic meter)} \frac{\text{Production}}{\text{Volume of waterconsumed by ET}} \quad (20)$$

3.3.2. Water Supply Indicators

During the growing season, the study assessed the Ujummo irrigation schemes' relative irrigation and water delivery. Water supply is the total of all provided water plus effective rainfall, whereas irrigation supply is the amount of water delivered directly from the water source. The CROPWAT 8.0 computer model is used to calculate the total crop water demand for a specific cropping pattern and irrigation intensity.

$$CWRmonthly = CWR \text{ maize} \times (area \text{ of maize}/area\ total) + CWR\text{potato} \times (area \text{ potato}/\ area\ total) + CWR\text{wheat} \times (area \text{ wheat }/area\ total) + CWR \text{ tomato} \times (area \text{ of tomato}/area\ total) + CWR\text{paper} \times (area \text{ paper}/\ area\ total)$$

$$IWD = (m^3) - Peff(m^3)$$

$IWS = DIW\ (m^3) + Peff(m^3)$ Both relative water supply and irrigation supply was determined using the following equation (Molden *et al.*, 1998).

$$RIS = (m^3)/(m^3)$$

$RWS = IWS\ (m^3)/CWR\ (m^3)$ Where: - RWS: Relative water supply (m^3); IWS: Irrigation water supply (m^3); IWD: Irrigation water demand (m^3); CWR: - Crop water requirement (m^3).

The water delivery capacity was computed from the main offtake canal capacity which was computed from the canal structure cross-section at the diversion intake by measuring the area, velocity and by considering freeboard. The peak monthly demand was computed by CROPWAT 8.0 model. It was calculated using equation recommended by [15].

$$\text{WDC} = \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak cosumptive demand}} \quad (21)$$

Physical indicators are related to the changing or losing irrigated land in the command area for different reasons. The irrigation ratio and sustainability of irrigated area, which can be expressed as the follows [15].

Irrigation Ratio (IR) Indicates the degree of utilization of the available irrigable area at a particular time. While there are several factors contributing to the variation in IR, availability of irrigation water is the major one, but even under sufficient water supply, low figures can be caused because of misuse [29].

Irrigation ratio is the ratio of currently irrigated area to the command area [15].

$$\text{IR} = \frac{\text{Irrigated cropped area}}{\text{Command area}} \quad (22)$$

Where: - Irrigated crop area (ha) is the portion of the actual irrigated land in any given irrigation season, Command area (ha) is the potential scheme command area.

Sustainability of irrigated area is the ratio of currently irrigable area to initially irrigated area. This important indicator mainly used to observe the status of the irrigation systems either contracted or expanded. The currently irrigable area and nominal irrigated area of Ujummo scheme was determined from Haru woreda Agricultural office. Sustainability of irrigated area was computed by using the following equation [1].

$$\text{SIA} == \frac{\text{Currently Irrigable area}}{\text{Initially Irrigated area}} \quad (23)$$

Where: - Current irrigable area is the area currently irrigated (ha); initially irrigated area is the designed/nominal/ irrigable area (ha).

4. Results and Discussions

The Ujummo Irrigation Scheme examined soil texture classes, revealing sandy loam in the head, middle, and tail. The average moisture content at FC and PWP was 35%, with mass base moisture and 22.67% respectively. Bulk density increased with depth, indicating soil compactness. The observed total accessible water content (TAW) was 123.9mm at a 30 cm soil depth, with values ranging from 38.16 to 45.54mm per soil depth Table 2.

Table 2. *Analysis of Soil physical properties of the scheme.*

Soil depth (cm)	% Particle sizedistribution			Textural Class	Bulk density (g/cm^3)	FC mass Base (%)	PWP mass Base (%)	TAW (mm/ depth)
	Clay	Sand	Silt					
0-30	24.0	42.5	33.5	Sandy Loam	1.06	33	21	38.16
30-60	26.5	45.0	28.5	Sandy Loam	1.11	35.1	23	40.293
60-90	27.0	42.0	31.0	Sandy Loam	1.15	37.2	24	45.54
Average	25.5	43.25	31.25	Sandy Loam	1.11	35.	22.67	123.9

4.1. Technical Performance Indicators

4.1.1. Conveyance Efficiency (Ce)

The outcomes revealed that the Scheme's lined main canal has 87.79% conveyance efficiency. The new finding is in line with previous research by Alebachew (2018), who found that the primary canal's water conveyance efficiency ranged from 77 to 96.6% with an average value of 86.2%. However, the average conveyance efficiency of the unlined secondary canal plan was only 80.1% due to seepage loss in the bed and side of the earthen canals and clogged by sediments. Similarly, observed that the unlined conveyance efficiency of the Mada Batu small-scale irrigation plan canals ranged from 47.1 to 88.6% by [23]. Additionally, the outcomes are consistent with [22] findings that the average water conveyance efficiency for main canals ranges from 86.26% to 96.02%. Overall, the scheme has a conveyance efficiency of 70.3%, which is very good efficiency recorded in the scheme.

However, for unlined, poorly managed main and field canals, the usual conveyance efficiency numbers that are typically given are 70 and 50%, respectively, whereas the statistics for well-managed canals are 85 and 80%, respectively [5]. The primary causes of the high water conveyance losses in the scheme's main and secondary canal were mostly poor construction, canals that became silted with dirt and weeds, cracked and broken sections at various locations, canals that were under designed with smaller Cross sections, which led to water overflow, severely damaged sides and beds from scouring caused by the steep bed slope, and a lack of drop structures and flow control structures. Losses through the conveyance system, which is in the main and secondary canal at Ujummo irrigation scheme, were 0.0244 and 0.15 l/s/m, respectively.

Table 3. *Conveyance efficiency of main canal of Ujummo irrigation scheme.*

Lt (m)	**V (m/s)**	**A (m2)**	**Qin (m^3/s)**	**Qout (m^3/s)**	**Ec (%) Qout/Qin*100**	**ΔQ/Lt (m^3/s)/m**	**ΔQ/Lt l/s/m**
	0.60	0.10	0.0603	0.0583	96.71	1.98616E-05	0.0199
100	0.32	0.18	0.0583	0.0570	97.84	1.25656E-05	0.0126
	0.49	0.12	0.0570	0.0569	99.81	1.0645E-06	0.0011
	0.34	0.17	0.0569	0.0568	99.77	1.31255E-06	0.0013
200	0.34	0.17	0.0568	0.0548	96.41	2.04056E-05	0.0204
	0.38	0.14	0.0548	0.0466	85.10	8.1605E-05	0.0816
400	0.42	0.11	0.0466	0.0463	99.25	3.5073E-06	0.0035
	0.41	0.11	0.0463	0.0438	94.69	2.45716E-05	0.0246
	0.39	0.11	0.0438	0.0425	97.14	1.25192E-05	0.0125
600	0.40	0.11	0.0425	0.0401	94.21	2.46429E-05	0.0246
	0.43	0.09	0.0401	0.0389	97.09	1.16566E-05	0.0117
	0.43	0.09	0.0389	0.0361	92.79	2.80707E-05	0.0281
800	0.45	0.08	0.0361	0.0343	94.92	1.83484E-05	0.0183
	0.52	0.07	0.0343	0.0327	95.31	1.60625E-05	0.0161
1000	0.34	0.10	0.0327	0.0255	78.02	7.17888E-05	0.0718
	0.44	0.06	0.0255	0.0110	43.25	0.000144646	0.1446
	0.27	0.04	0.0110	0.0107	97.04	3.26665E-06	0.0033
1200	0.35	0.03	0.0107	0.0101	94.61	5.76066E-06	0.0058
	0.46	0.02	0.0101	0.0061	60.11	4.03693E-05	0.0404
1400	0.25	0.02	0.0061	0.0033	54.14	2.78914E-05	0.0279
	0.20	0.02	0.0033	0.0023	71.26	9.46332E-06	0.0095
1600	0.16	0.01	0.0023	0.0021	89.12	2.55376E-06	0.0026
	0.15	0.01	0.0021	0.0019	89.38	2.22178E-06	0.0022
1800	0.14	0.01	0.0019	0.0017	88.95	2.06616E-06	0.0021
Average					87.79		0.0244

The established a range of allowable conveyance losses with a mean conveyance efficiency of 80% or unlined canals for clay loam soils [37]. This led to the conclusion that the conveyance loss via the Ujummo irrigation scheme's lined main canal exceeded the allowable range.

Field observation revealed this situation: seepage, over topping, silt deposition, water loss through canal gate, usage for animal drinking and washing, and accumulation of boulders along the main canal of the Ujummo small-scale irrigation project. The primary causes of less canal conveyance efficiency is canal waterways' expanding sizes include water stagnation, grass covers, unlawful water turnouts, excessive sedimentation, faulty control gates, and evaporation losses. Unlined canal sections lose more water, widening their cross section and increasing water stagnation. The conveyance efficiency and losses findings reveal significant irrigation water losses, potentially impacting irrigation adequacy, we noticed lowered conveyance efficiency in this study compared to prior research findings in Ethiopia [20, 22].

Table 4. *Secondary canal conveyance efficiency of ujummo irrigation scheme.*

Lt (m)	v (m/s)	A (m2)	Qin (m^3/s)	Qout (m^3/s)	Ec (%) Qout/Qin*100	ΔQ/Lt (m^3/s)/m	ΔQ/Lt l/s/m
10	1.326	0.0079	0.01050	0.010123	96.452	0.00004	0.037238
10	1.123	0.0082	0.00921	0.007595	82.445	0.00016	0.161724
10	0.855	0.0090	0.00766	0.006759	88.234	0.00009	0.090135
10	0.687	0.0102	0.00703	0.006667	94.765	0.00004	0.036828
10	0.543	0.0155	0.00840	0.004764	56.716	0.00036	0.363584
10	0.437	0.0134	0.00585	0.004550	77.715	0.00013	0.13047
10	0.433	0.0153	0.00664	0.004280	64.467	0.00024	0.2359
Average					80.113	0.00015	0.15084

4.1.2. Application Efficiency (Ea%)

The results of this finding, the Ujummo irrigation scheme's at head, midle and tail 38.91%, 37.78%, and 39.16% average application efficacies were 38.62% (Table 5). The new findings are consistent with those of [36], who state that the application efficiency of the furfuro and Bilate irrigation schemes was 58% and 55.9%, respectively, which is close to this finding. The data from [27] indicate that 44-70% might be the application effectiveness of furrow irrigation. The study's average field application efficiency below within the previously specified suggested level. The Ujummo irrigation system, however, was shown to be below the range. The main reasons for the irrigation systems' low application efficiency were bad design, poor management, a lack of water measurement and control structures, inadequate schedule maintenance, and a lack of scientific irrigation scheduling. Based on the study's application efficiency, it is necessary to implement improvements for daily operations and on-field water management.

4.1.3. Water Storage Efficiency (Es)

As stated in the analysis, the average water storage efficiencies for the ujummo irrigation scheme were 66.14%, 55.96%, and 61.12% in the head, middle, and tail fields, with average storage efficiency of 61.1 respectively (Table 5). As a result, for range irrigation schemes, the water storage efficiencies found in this study were near to these results. In general the storage efficiency of schemes was very good as compared to 63% storage efficiency usually found in typical furrow irrigation systems [25, 19]. This normally shows over irrigation of the field and this might be associated with the intention of the farmers on high return from high irrigation depth and the soil moisture deficiency in the irrigation schemes may have been somewhat filled by the applied irrigation water. This indicates both the stress on soil moisture and the amount of irrigation water used appropriately.

Table 5. *Application and storage efficiency of Ujummo irrigation scheme.*

Application efficiency				Storage efficiency		
Field location	Ws (mm)	Wf (mm)	Ea%	Ws (mm)	Wn (mm)	Es%
Head	32.84	84.4	38.91	32.84	49.65	66.14
Middle	27.73	73.40	37.78	27.73	49.55	55.96
Tail	26.78	68.40	39.15	26.78	43.82	61.12

Application efficiency				Storage efficiency		
Field location	Ws (mm)	Wf (mm)	Ea%	Ws (mm)	Wn (mm)	Es%
Average			38.61			61.1

Ws depth of water stored in root zone, Wf depth of irrigation water, Wn depth of water needed before next irrigation.

4.1.4. Water Distribution Uniformity (DU)

The variance in supply amounts or application depths is expressed by irrigation uniformity. By measuring the amount of water that infiltrated the root zone using the soil moisture content, the irrigation scheme's uniformity was assessed. Consistent application of irrigation water in a field contributes to consistent crop growth and stand. The irrigation uniformity for Ujummo in this research ranges from 90.85 to 91.14%, with an average value of 90.68%. In comparison to the sophisticated furrow irrigation systems, which have an irrigation uniformity of 70% according to [25], the irrigation uniformity statistics observed in this study's scheme are significantly greater.

Similar findings were obtained by several investigations [12, 18, 23, 24, 26, 33, 34]. With water distribution consistency above 90%. In general the distribution uniformity of ujummo irrigation scheme was excellent due to the short furrow length meters, closed furrow ends, and significant stream flow.

Table 6. *Distribution uniformity of ujummo irrigation scheme.*

water stored at each point						mean	DU %
head	17.04	17.73	19.00	21.11	21.19	19.21	90.85
Middle	16.46	16.57	18.08	19.16	20.74	18.20	91.14
Tail	13.8	14.9	15.7	17.31	18.17	15.98	90.06
Average							90.68

4.1.5. Deep Percolation Ratio (DPR)

A deep percolation ratio shows how much of a field's administered irrigation seeps into the soil beneath the root zone. It was discovered that the irrigation scheme's average deep percolation ratio was 61.38%. A high deep percolation ratio in the schemes suggests over-irrigation. According to the results, there was a decrease in application efficiency with a larger deep percolation ratio. Some irrigators in the Ujummo scheme were seen during the study period attempting to remove extra water from their crops by excavating conventional drainage ditches. Because of this, there is a high deep percolation ratio, a sign of over watering, which has led to a problem with water logging.

4.1.6. Project Efficiency (Ep)

For Ujummo irrigation schemes, the study's overall irrigation efficiency was 27.14%. This outcome is consistent with [36], who state that the overall efficiency of the furforo and bilate irrigation schemes is 32% and 28 percent, respectively. According to [9], an overall irrigation efficiency of 50-60% is considered acceptable overall, 40-50% is reasonable, and 20-30% is poor. As a result, the study's total irrigation efficiency were low; water loss in conveyance systems may be the cause.

4.2. External Performance Indicators

4.2.1. Agricultural Output Indicators

The average discharge was calculated to be 0.0603 m^3/s after the discharge at the head of the diversion canal was measured. And the amount of water diverted in 2022-2023 was estimated using this outflow. The farming practices of the farm are separated into two seasons based on the information gathered regarding the planting and harvesting of each crop during the year under study. October through January is the first agricultural season, and February through May is the second. During these months, the amount of water is diverted.

Season-1 =0.0603*110*12*60*60=286,545.6m^3 and Season-2=0.0603*100*12*60*60=260,496m^3

To calculate the first four indicators gross production was taken as SGVP and the total output of the ujummo irrigation scheme were exhibited in table below:

Table 7. The total output of ujummo irrigation scheme in 2022/2023 crop season.

crop type	area (ha)	Production in (Qt)	Price Qt in ETB	Total out put in ETB	Total out put in $
Wheat	21.4	350	3300	1155000	21099.74
cabage	2.23	48	1080	51840	947.0223
paper	0.75	7.8	1800	14040	256.4852
tomato	1.21	35	2100	73500	1342.711
maize	22.5	380	3100	1178000	21519.91
potato	11.3	338	1800	608400	11114.36
total	59.39			3080780	56280.2

The broader cropping pattern utilized by the farm is evident from the observation. The entire year is divided into two seasons based on the dates of planting and harvesting of each crop, and the CWR and irrigation requirements of each were determined using CROPWAT 4.2. Next, for every irrigated crop and growing season, the net irrigation needs (IR) and the net crop water requirements (CWR) are calculated.

Table 8. Crop water requirement and irrigation water requirement of each crop in season.

	season-1					
crop type	area (ha)	NCWR (mm) season	NCWR (m^3)	NIR (mm)/ season	NIR (m^3)	Peff (m^3)
Wheat	21.4	261.42	55943.06	252.13	53956.60	1661.21
cabage	2.23	32.64	727.77	31.25	696.87	2.69
paper	0.75	14.31	107.33	13.26	99.42	0.23
tomato	1.21	22.45	271.65	22.44	271.54	0.000
Total	25.59	330.81	57049.81	319.08	55024.42	1664.13
season-2						
crop type	area (ha)	NCWR (mm) season	NCWR (m^3)	NIR (mm) season	NIR (m^3)	Peff (m^3)
maize	22.5	235.1	52901.6	109.2	24570.0	36545.86
potato	11.3	107.1	12107.9	99.59	11254.1	285.44
total	33.8	342.3	65009.5	208.79	35824.1	38495.42

(i). Output per Unit Irrigated Area

The irrigation plan yielded an average production value per unit-irrigated area of 947.64US$ /ha (Table 9). Based on the review, it can be concluded that the income per irrigated area plan was superior since farmers had more experience using irrigation water. According to the study done on irrigation schemes for the Southeastern Anatolia project, there was a range of

(308-5771 US$/ha) in the production per irrigated area among the different irrigation schemes. As a consequence, the study's findings showed that the variance in output per irrigated area across the two irrigation systems was within suggested range [27]. The output per unit irrigated area varied from one project to another due to fluctuations in the crop pattern and world prices of the base crop.

(ii). Output per Unit Command Area

Table 9 shows that the output per unit command area values were 1324.24$/ha. As to the study's findings, there are more yields per unit of command area as compared to irrigated land. This demonstrates that the increase of the irrigated area in Ujummo irrigation schemes by 17.2 hectares in comparison to the planned command area has an impact without supplying more irrigation water. According to [27], the range of possible variations in the production per unit command area across different irrigation systems is between 1223 and 9436 US$/ha. As a consequence, the study's findings demonstrated that the range indicated for output per unit variation in command area irrigation schemes was met. This outcome is also consistent with the findings of [3], who reports that the production per unit command area in the Fesas and Mugie irrigation schemes was 989 $/ha and 1046 $/ha, respectively.

(iii). Output per Unit Irrigation Diverted

This study's production per unit irrigation supply an average of 0.103 US$/m^3. After studying 60 irrigation schemes in the Kizilirmak Basin of Turkey, by [21], proposed that the range of values for production per unit of irrigation supply may be between 0.03 and 2.21 US$/m^3. As a consequence, the production per irrigation supply result fell within the advised range of thus studies. [3], also reported the output per unit irrigation water diverted values for the Mugie and Fesas irrigation schemes, which were 0.22 and 0.26 $/m^3 respectively, and they were nearly identical to these results.

(iv). Output per Unit Water Consumed

The study's output per unit of water utilized was found to be 0.67 US$/m^3. [1], proposed that the range of 0.03-0.91 US$/m^3 might be the yield per unit of water spent for irrigation projects. As a consequence, the production to water used ratio for the Ujummo irrigation plan fell within the advised range. Water productivity is defined as the output per unit of water used and the output per unit of irrigation supply, whereas land productivity is defined as the output per unit of command area and irrigated area.

Table 9. The results of agricultural output indicators of ujummo irrigation scheme.

output per unit irrigated area ($/ha)	output per unit command area ($/ha)	output per unit irrigation diverted ($/m^3)	output per unit water consumed ($/m^3)
947.64	1324.24	0.103	0.67

4.2.2. Water Supply Indicators

According to Table 10, which analyzed the findings of the water delivery indicators (relative water supply and relative irrigation supply), the Ujummo irrigation scheme's relative irrigation supplies were 15.91. According to [1] any irrigation scheme is preferable to have a relative irrigation supply value of one over one with greater or lower values. The study's findings demonstrate that this irrigation strategy required a higher relative amount of irrigation supplies. This showed that, in an irrigation scheme, the applied water is matched to the irrigation water requirement. The relative water supply figures for the Ujummo irrigation projects were 10.89. This finding suggested that agricultural water demands in irrigation systems had been met by the total amount of irrigation water applied plus effective rainfall.

Relative water supply measures the degree to which irrigation supply and demand are balanced. A number greater than 1 suggests that irrigation is being provided in excess, which might lead to waterlogging and poorer yields; a value less than 1 suggests that crops are not receiving enough water. A water supply that is more than 2.5 times more than a demand is not a suitable signal for water management, according to [4]. found that the relative water supply ranged from 0.29 to 1.67 in similar investigations. In a different research, [39, 30] found that the relative water supply in 158 irrigation schemes ranged from 0.91 to 7.15. The irrigation systems for Mexico's Salava Tierra (4.1) and Malaysia's Muda (0.8) had the greatest and lowest relative water supply values, respectively [1].

Table 10. *Water supply indicators of ujummo irrigation scheme.*

IWS (m^3)	DIW (m^3)	IWD (m^3)	RIS	RWS
1329311.43	1290816	83563.90	15.91	10.89

Where:- IWS Irrigation water supply, DIW Diverted irrigation water, IWD Irrigation water demand, RIS Relative Irrigation supply and RWS Relative water supply.

Water Delivery Capacity Indicator.

Irrigation Ratio

Table 11 shows that the irrigation ratio for the Ujummo irrigation project was 1.34. This indicates that 134% of the planned command irrigation scheme was actually watered throughout the study season. This indicates that in irrigated fields were increased. The causes might include surrounding farmers' desire in irrigating additional land outside the planned area, as well as the self-initiative and interest of farmers inside the schemes command areas to irrigate their land owing to excellent land productivity as greater soil fertilities of the locations and two cropping season used. This outcome is consistent with the reports by [36, 17] for the Bilate and Kulech systems.

Table 11. *Water delivery capacity indicator.*

peak demand flow rate (l/s)	Canal Delivery Capacity (l/s)	WDC (%)	Irrigated crop area (ha)	Current irrigated area (ha)	Command area (ha)	RI	SIA
29.1	60.3	207.2	59.39	34.9	42.5	1.34	0.82

4.3. Physical Indicators

Sustainability of irrigation area

Table 11 shows that the irrigated area under the Ujummo irrigation project has sustainability score of 0.82. This suggests that 82% of the initially irrigated land in the irrigation plan was actually watered throughout the study season. As a result, the schemes' irrigated areas were less than their original irrigated area.

5. Conclusions

This study used both internal and external factors to assess the Ujummo irrigation scheme in West Wolega, Ethiopia. At the beginning, middle, and end of every scheme, three typical farmer's fields were chosen. The scheme's low application, water storage, and transportation efficiencies and losses were demonstrated by the findings. Internal performance indicators showed inefficiency and subpar performance, which may have been brought on by canal grass cover, high sedimentation, illegal water turnout, low crop water demand, ignorance, and water stagnation. The crop water demands and peak consumptive usage were met by the applied irrigation water, according to external performance measures. The plan did, however, increase the irrigated lands, and the output per unit command area was higher than the output per unit irrigated area.

Abbreviations

CWR	Crop Water Requirements
DU	Distribution Uniformity
DR	Deep Percolation Ratio
WDC	Water Distribution Capacity
RI	Relative Irrigation
SIA	Sustainable Irrigated Area

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Molden DJ, Sakthivadivel R, Perry CJ, et al. Indicators for comparing performance of irrigated agricultural systems. Iwmi; 1998.

[2] Feyen J, Zerihun D (1999). Assessment of the performance of border and furrow irrigation systems and the relationship between performance indicators and system variables. Agric Water Manag. 40(2-3): 353-62.

[3] Mekonen BM, Gelagle DB, Moges MF (2022). The current irrigation potential and irrigated land in Ethiopia: areview. Asian J Adv Res 12(6): 1-8.

[4] Levine G. (1982). Relative water supply. An explanatory variable for irrigation systems. Technical Report No. 6. Ithaca, New York, USA: Cornell University.

[5] Moges MF. (2022). Indicators for evaluating the performance of small scale irrigation schemes. J Agric Sci Bot. 2022; 6(8): 136.

[6] Allen, R. G., Preira, L. S., Raes, D. and Smith, M. 1998. Crop Evapotranspiration- Guidelines for Computing Crop Water Requirements. FAO 56. Rome, Italy: FAO.

[7] Harrelson, C. C., Rawlins, C. L. and Potyondy, John P. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. RM-245. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p. ILRI, the Netherlands.

[8] Ingle, P. M., Shinde, S. E., Mane, M. S., Thokal, R. T. and Ayare, B. L. 2015. Performance Evaluation of a Minor Irrigation Scheme. Research Journal of Recent Sciences. 4: 19-24.

[9] Rai RK, Singh VP, Upadhyay A (2017) Planning and evaluation of irrigation projects: methods and implementation. Academic Press.

[10] Michael, A. M. Irrigation theory and practice. Evaluating land for irrigation comman ds. vikas publishing house pvt ltd, New Delhi. 1997.

[11] Jaiswal, P. C. 2003. Soil, Plant and Water Analyses. Ludhiana Kalyani publishers. New Delhi, India.

[12] Menelik Hailu. 2008. Performance Evaluation of Small-Scale Irrigation Scheme: A Case Study of Selgie Irrigation Scheme, South Wollo. M. Sc. Thesis. Haramaya University.

[13] Michael, A. M. 2008. Irrigation theory and Practice, Second edition VIKAS Publishing house Pvt Ltd. India.

[14] Jurriens M, Zerihun D, Boonstra J,. Surdev: surface irrigation software; design, operation, and evaluation of basin, border, and furrow irrigation. ILRI; 2001.

[15] Bos MG. Performance indicators for irrigation and drainage. Irrig Drain. 1997; 11(2): 119-37.

[16] FAO (Food and Agricultural Organization). Guidelines for designing and evaluating surface irrigation systems: Irrig Drain. 1989; 45.

[17] Minichil Taye. (2019). Evaluating and comparing the performance of small scale irrigation systems: a case study Jedeb and Kulech small scale irrigation schemes in East Gojam Zone. MSc Thesis. Bahr Dar University. Bahri Dar, Ethiopia. 114p.

[18] Kenneth HS 1988. Irrigation Systems and water application efficiencies. California State University, Fresno, California.

[19] Alemayehu Serbessa. Performance evaluation of irrigation system (Welenchity Surface Irrigation Scheme). MSc. Thesis. Addis Ababa University. 2018.

[20] Ahmed, B., 2017. Bayan Ahmed Technical Performance Evaluation of Mada Batu Small Scale Irrigation Scheme, West Arsi Zone of Oromia Region. Int. J. Eng. Res. 5.

[21] Cakmak Belgin, Beyribey, Mevlut Yildirim, Yasin. (2004) Benchmarking Performance of Irrigation Schemes: A Case Study from Turkey. Irrigation and Drainage. 163: 155-163.

[22] Alebachew, S., Ing, P. S., 2018. Evaluation of canal water conveyance and on-farm water application for a small-scale irrigation scheme in Ethiopia. Int. J. Water Resour. Environ. Eng. 10, 100-110.

[23] Bayan Ahmed. 2017. Technical performance evaluation of Mada Batu small-scale irrigation scheme, West Arsi zone of Oromia Region. International Journal of Engineering Research-Online. Vol. 5, Issue. 3.

[24] Muhammedziyad Geleto, Mihret Dananto, Demisachew Tadele (2019). Performance evaluation of selected surface irrigation schemes in Kacha Bira Woreda, SNNPRS, Ethiopia. Discovery Science, 15, 16-25.

[25] Raghuwanshi, S. and W. Walender, 1998. Optimal furrow irrigation scheduling under heterogeneous conditions, Agricultural Systems, 56: 39-35.

[26] Kandiah K., 1981. Evaluation of furrow irrigation system for cotton, Melka Werer Research Station, IAR, Ethiopia.

[27] Değirmencİ H, Büyükcangaz H, Kuşcu H (2003) Assessment of Irrigation Schemes with Comparative Indicators in the Southeastern Anatolia Project. Turkish J Agric For. 2003; 27(5).

[28] Awulachew S., Yilma A., Loulseged M., W. Loiskandl, Ayana., Tena A., 2007. Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. IWMI Working Paper 123.

[29] Zeleke AD, Bart S, Laszlo H. Comparative irrigation performance assessment in community-managed schemes in Ethiopia. J Afr Agric Res. 2012; 7(35): 4956-70.

[30] Eshetu Adane Kibret, Abebech Abera, Workineh Tadesse Ayele, Neway Asrat Alemie (2021) Performance evaluation of surface irrigation system in the case of Dirma small-scale irrigation scheme at Kalu woreda, northern Ethiopia. Water Conserv Sci Eng 6:263-274.

[31] USBR. 2014. Parshall flumes-United States Bureau of Reclamation. http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/chap08_10.html

[32] WWAP (United Nations World Water Assessment Programme). 2012. The United Nations World Water Development Report 4. Managing Water under Uncertainty and Risk. UNESCO, Paris.

[33] Worku Negussie. 2013. Technical Performance Evaluation of Midhegdu Small-scale Irrigation Scheme in West Hararge Zone, Oromia Region, Ethiopia. M. Sc. Thesis. Haramaya University.

[34] FAO (Food and Agriculture Organization). 2011. Irrigation Manual: Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation. Volume II Module 7. Harare.

[35] Dessalew, T., Ayalew, A., Desalegn, T., Mathewos, M. and Alemu, G. 2016. Performance Evaluation of Bedene Alemtena Small Scale Irrigation Scheme in Hallaba Special Woreda, Southern Ethiopia. Open Access Library Journal, 3: e2021.

[36] Abo, M. A., Assefa, S. and W/Michael, A., 2024. Performance evaluation of the Bilate and Furfuro irrigation schemes in Silti Zone, southern Ethiopia. Journal of Engineering and Applied Science, 71(1), p. 88.

[37] Wachyan, E., Rushton, K. R., 1987. Water losses from irrigation canals. J. Hydrol. 92, 275-288. https://doi.org/10.1016/0022-1694(87)90018-7

[38] Tesfaye, H., Dananto, M., Woldemichael, A., 2019. Comparative Performance Evaluation of IrrigationSchemes in Southern 8, 2-6. https://doi.org/10.4172/2168-9768.1000232

[39] Miller, H., 2001. Evaluation of transferred irrigation networks with comparison indicators. Journal of Uludag University Faculty of Agriculture, 15, pp. 31-41.