

Research Article

Performance Evaluation of Woybo Irrigation Scheme: Wolaita Zone, Southern Ethiopia

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Abstract

Performance evaluation of irrigation scheme is vital for realizing the present status and identifying the area for improvement. The study was conducted in Woybo irrigation scheme which is located in Boloso Sore district, Wolaita zone, Southern Ethiopia. This study was aimed to evaluate the performance of Woybo irrigation scheme with internal performance indicators. A total of nine demonstrating farmers' fields were selected from three canal reaches (head, middle, and tail) through purposive sampling. Primary and secondary data were collected, recorded, and analyzed. To measure the water applied to each experimental field, Parshall flume was installed, and soil samples were taken to determine soil texture, field capacity, permanent wilting point, and soil moisture content before and after each irrigation event at regular soil depth intervals. The results revealed that the mean conveyance efficiency was 60.85% and the application efficiency was 48.53%. Water distribution uniformity, deep percolation, and storage efficiencies were 84.56%, 51.47%, and 85.22%, respectively. However, the overall irrigation efficiency was found to be 29.53%, which was poorly performed due to inadequate water application, ineffective field water management, and low efficiency in water delivery systems. The main factors contributing to the poor water delivery performance included failures in water regulating gates, leakages, and siltation of canals. To address these problems, recommendations are made such as improvements in water application techniques should be implemented, through proper irrigation scheduling, water conservation practices, surge irrigation techniques, and providing extension support, training, and experience sharing. Additionally, maintenance and lining of earthen canals are necessary, along with the replacement and repair of leakages and broken water regulating and controlling structures. These measures can help to upgrade water delivery efficiency and improve the overall performance of the irrigation scheme.

Keywords

Efficiency, Evaluation, Internal Indicators, Irrigation Scheme and Performance

1. Introduction

Ethiopia is endowed with ample water resources, and cultivable land. According to current investigation, the country has the estimated amount of 124.4 billion cubic meter (BCM)

of river water, 70 BCM lake water, and 30 BCM groundwater resources [1]. It has huge amount of both surface and ground water resources but the status of utilization is in infant level. It

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is noticeably that the development of the country is never go far without utilization of water resources properly. But, the country is not used their water resources properly due to different political, natural, technical and economic factors. However, the current situation of the water sector development programs are performing well to increase the water utilization potential and different eye opening future opportunities to develop the water resources infrastructure and utilization [2].

Evaluating and improving the performance of existing schemes is a smart way of promoting sustainable development and used as a bench mark for further irrigation improvement. The irrigation schemes are being under low productivity due to absence of experience in design, operation, maintenance and limitation on modern irrigation water management (irrigation scheduling techniques, water saving irrigation technologies, water measurement techniques), and low performance of schemes [3].

Performance evaluation is the systematic analysis of an irrigation system based on measurements taken under field conditions and practices normally used and comparing the same with an ideal one. It is determined by the efficiency with which water is diverted, conveyed, and applied, and by the adequacy and uniformity of application in each field on the farm [4].

Poor irrigation water management associated with water scarcity is the major reason for underperformance of most small-scale irrigation schemes in Ethiopia [5]. Also, poor management of available water for irrigation, both at system and farm level has led to a range of problems and further aggravated water availability and has reduced the benefits of irrigation investments [6].

Nowadays, understanding the performance of existing scheme is crucial to identify key problems that impede scheme efficiencies and the utilization of available resources. Therefore, the aim of this study was to conduct the performance evaluation of Woybo irrigation scheme in the case of Boloso Sore district, Wolaita Zone, Southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The study irrigation scheme is found in Boloso Sore district, Wolaita Zone, Southern Ethiopia. It is located about 300km south of Addis Ababa, the capital city of Ethiopia. Geographically, it is positioned at latitude $6^{\circ}05'0''$ - $7^{\circ}11'0''$ N and longitude $37^{\circ}0'0''$ - $37^{\circ}50'0''$ E [7]. It covers an area of 27,030 ha, with an average altitude of 1830 masl and human population of 211,643 (102,206 male and 109,437 female) [8].

Woybo River is one of the tributaries of the Omo-Gibe basin, a perennial river that originates from a small spring located near Mount Damot in Wolaita. A diversion weir was constructed on the Woybo River, covering a total command area of 190 ha. The weir is situated 17 km away from Areka

town, the capital city of Boloso Sore district.

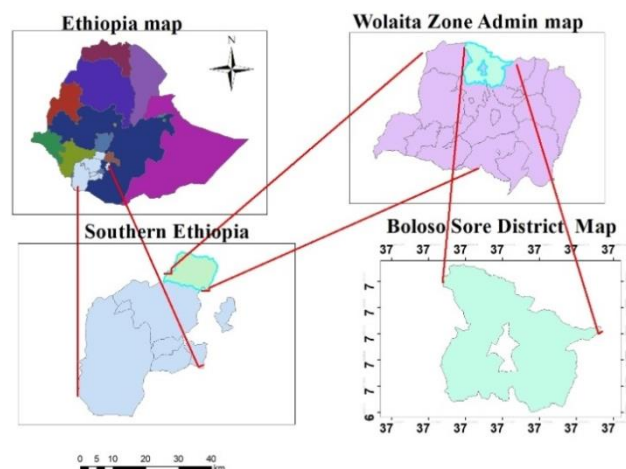


Figure 1. Location map of the study area.

The scheme was designed to benefit two districts, Boloso Sore and Boloso Bombe. While the majority of the irrigated land is located in Metala Hembecho kebele (Boloso Sore district), previously farmers from Ajora kebele (parts of Boloso Bombe) had been benefiting from the scheme. However, due to a current canal maintenance problem, only farmers or water users from Hembecho kebele are currently benefiting.

2.2. Methods of Data Collection

Both primary and secondary data were collected during irrigation season of 2021/2022. Primary data were obtained through regular measurement s of water discharge, soil texture, soil moisture, and observation of scheme status. All necessary secondary data were collected from various sources, including the Kebele, Agricultural and Natural resource office, Water and Irrigation Office at the district, Zone, and regional levels, as well as from published and unpublished reports and books.

2.2.1. Soil Textural Classes

Soil textural analysis was performed using the hydrometer method. For this study, three sampling fields were selected from each canal reach (head, middle, and tail) along the scheme.

Composite samples were collected from each selected farmers' field in a diagonal fashion using auger with a depth interval of 30cm, covering the maize root zone up to 120cm [9], as maize is the dominant crop in the area. The textural class was determined using the USDA textural triangle method [10].

2.2.2. Bulk Density of the Soil

Undisturbed samples were taken respective soil depth by

core samplers from selected fields and taken to laboratory, placed in oven dried at 105 °C for 24 hours and analyzed by Jaiswal [11].

$$Bd = \frac{\text{Weight of oven-dried soil(gm)}}{\text{Volume of soil in the core (cm}^3\text{)}} \quad (1)$$

Where: Bd: - Bulk density of soil (gm/cm³)

2.2.3. Soil Moisture Content Determination

The samples for soil moisture determination were taken by an auger from selected locations of the furrow at the head, middle and tail reaches of farms at depth interval of 0-30, 30-60, 60-90, and 90-120 cm. Soil moisture was measured before and after two days of irrigation events using gravimetric methods [12].

$$\theta_v = \left(\frac{W_w - W_d}{W_d} \times 100 \right) \times Bd \quad (2)$$

Where, θ_v : -Volumetric moisture content (%),

W_w : -Wet weight of the soil (g),

W_d : - Oven dried weight of the soil (g) and Bd: Bulk density of soil (g/cm³).

2.2.4. Field Capacity and Permanent Wilting Point

Field capacity and permanent wilting point of soil status were determined and analyzed using a pressure plate apparatus in the soil laboratory. Then, after getting result, the total water holding capacities of the soil was estimated as follows:

Total Available Soil Water: is the total amount of water a crop can use from the soil and was calculated by Walker [12].

$$TAW(mm) = \sum_i^4 (\theta_{FC} - \theta_{pwp}) \times D_i \quad (3)$$

Where, TAW: - Total Available Water (mm),

θ_{FC} : Soil moisture at field capacity (decimal)

θ_{pwp} : Permanent wilting capacity (decimal)

D_i : - Depth of ith soil layer (mm),

i : -Integer, 1 to 4 and $n = 4$ soil layers in root zone.

Readily available water was computed by [9].

$$RAW = TAW \times P \quad (4)$$

Where: P (%) is of allowable moisture depletion for no stress.

2.2.5. Discharge Measurement on Canal

The discharge of water in the canal was measured by determining cross sectional area and average velocity of water in the main, secondary, and tertiary canals using the continuity equation.

$$Q = V \times A \quad (5)$$

Where, Q:-discharge (m³/sec), V: - Average velocity of water (m/sec), and A: wetted cross sectional area (m²).

Floating technique was used to measure velocity of water in the canal segments [13].

$$V_s = \frac{\text{Distance (m)}}{\text{average time(sec)}} \quad (6)$$

Where: V_s : The surface water velocity (m/sec), L: Known distance (10m) and t: - Average travel time (sec).

Since, surface water flows faster than subsurface water. Then, surface water velocity was multiplied by correction factors (C_f) 85% for rough or rocky bottom as suggested by Harrelson [14].

$$V_a = C_f \times V_s \quad (7)$$

Where: V_a : - Average water velocity (m/s).

2.2.6. Flow Measurement by Par Shall Flume

A Parshall flume (PF) was installed at selected farmers' fields to measure the amount of water applied during each irrigation event. It was positioned in a straight and leveled manner at the entrance of the experimental field. Using 3-inch PF, the average water height and irrigation duration were recorded while passing through it, and the area of the field was measured. The relationship between water height and discharge is given by Walker [12].

$$Q = C_f \times w \times h_u^{nf} \quad (8)$$

Where: Q: - flow rate in l/sec, W: throat width, C_f : free flow coefficient, h_u : - upstream water flow depth (m).

Depth water applied was determined as follow:

$$D_a = \frac{60 \times Q \times t_{ap}}{A_f} \quad (9)$$

Where: D_a : - Depth of water applied (mm),

Q: - Discharge rate (l/sec),

t_{ap} : - Application time (minute) and

A_f : -Area of field (m²).

2.3. Water Delivery Indicator Analysis

2.3.1. Conveyance Efficiency (E_c)

It indicates water delivering efficiency from diversion point to the field. It was measured through discharge rate (Q_{in}) that enters and (Q_{ou}) that leaves along a canals. Then, efficiency was estimated by Michael [15].

$$E_c(\%) = \frac{\text{Discharge outflow(l/sec)}}{\text{Discharge inflow(l/sec)}} \times 100 \quad (10)$$

The overall conveyance efficiency of the schemes:-

$$E_c = E_m \times E_s \quad (11)$$

Where: E_c : - Overall conveyance efficiency (%)

E_m : - Main canal efficiency (%), and

E_s : - Secondary canal efficiency (%)

2.3.2. Water Losses in the Canal System

Water losses in the canal system were determined in 100m testing segment.

$$Ql = \frac{Q_{in} - Q_{ou}}{L} \quad (12)$$

Where, Ql : - Water loss rate in channel (l/s/100m)
 Q_{in} : - Inflow to the segment (l/sec), Q_{ou} : - Outflow from the segment (l/sec) and L : - Length of canal (m).

2.4. On-Farm Water Management Analysis

In order to evaluate on-field water management practice, experiments was done by dividing whole canal reaches into three parts (head, middle, and tail end users) respect to the water source. A total of nine farmers' fields were purposively selected based on similar crop types, growth stage and the willingness of farmers.

2.4.1. Application Efficiency (E_a)

It indicates that how much water is actually stored in the root zone after irrigation. It is influenced by design and water management practices of farmers and it was calculated [16].

$$E_a(\%) = \frac{\text{Depth of water stored, } D_s \text{ (mm)}}{\text{Depth of water applied, } D_a \text{ (mm)}} \times 100 \quad (13)$$

Depths of water stored in the soil profile of the root zone (D_s) were calculated according by Walker [13].

$$D_s = \sum_{i=1}^4 \left(\frac{W_{ai} - W_{bi}}{100} \right) \times B_{di} \times D_i \quad (14)$$

Where, D_s : - Depth of water stored in crop root zone soil profile (mm),

W_{ai} and W_{bi} : - Moisture of i^{th} soil layer after and before irrigation (g/g, %), respectively.

B_{di} : - Bulk density of the i^{th} soil layer (g/cm³),

D_i : - Depth of i^{th} soil layer (mm), and

i : - Integer, 1 to 4 and $n = 4$ layers in the root zone.

2.4.2. Water Storage Efficiency (E_s)

It is an index used to measure irrigation adequacy. It was computed [16]:

$$E_s(\%) = \frac{\text{Water stored, (mm)}}{\text{Water required prior to irrigation, (mm)}} \times 100 \quad (15)$$

Depth of water stored in the soil profile was estimated by as

equation 14 in the above.

Depth of water required in the root zone prior to irrigations events was calculated [12].

$$D_{req} = \sum_{i=1}^4 \left(\frac{\theta_{FC} - \theta_{Bi}}{100} \right) \times D_i \quad (16)$$

Where; D_{req} : Depth of water required in the root zone prior to irrigation (mm),

θ_{FC} : - Moisture content at field capacity (%),

θ_{Bi} : - Moisture content before irrigation (%)

D_i : - Depth of soil profile in root zone (mm) and

i : - Integer, 1 to 4 and $n = 4$ soil layers

2.4.3. Distribution Uniformity (DU)

It describes how evenly water is applied by considering effective root depth as zone of water distribution.

To determine water stored in the root zone, three representative furrows were selected by *stratified sampling techniques* from each field at inlet, middle and tail of a furrow, divided by three equal parts and nine sampling points were selected from each farmer's field. A totally of 36 soil samples were taken from soil depth of 0-30, 30-60, 60-90 and 90-120 cm after an irrigation event from individual farmers field.

Then, water stored at nine sampled points were arranged in descending order and averages of least-water stored quarter of the fields were obtained.

Finally, distribution uniformity was computed [17].

$$D_u(\%) = \frac{DL_q}{D_m} \times 100 \quad (17)$$

Where: D_u (%):- Distribution uniformity

DL_q : - Mean depth of least-quarter of water stored (mm)

D_m : - Mean depth of water stored for nine sampled (mm)

2.4.4. Deep Percolation Ratio (DPr)

According to Feyen and Dawit, the two main types of water losses through furrow irrigation practice are runoff and deep percolation losses [18]. In the study area, farmers typically practiced tail closed furrow types. As formulated by these authors, it was calculated indirectly using application efficiency (E_a , %), assuming that water losses by runoff ratio (RR) were considered as zero [18].

$$DPr = 100 - E_a - RR \quad (18)$$

Where, DPr = Deep percolation ratio,

2.5. Overall Scheme Efficiency

It indicates the efficiency of the overall irrigation system and was calculated according by Imark [15].

$$E_p = \frac{E_c \times E_a}{100} \quad (19)$$

Where: E_p : - Overall scheme efficiency (%),
 E_c : - Overall conveyance efficiency (%),

E_a : - Average application efficiency (%) of the scheme.

Table 1. Soil Textural classes and bulk density.

Canal location	Soil depth (cm)	Bulk density g/cm ³	Particle size distribution (%)			Textural class
			Sand	Clay	Silt	
Head	0-30	1.10	30	52	18	Clay
	30-60	1.16	26	44	30	Clay
	60-90	1.22	28	48	24	Clay
	90-120	1.26	22	48	30	Clay
	mean	1.19				
Middle	0-30	1.08	24	40	36	Clay
	30-60	1.18	26	42	32	Clay
	60-90	1.19	20	52	28	Clay
	90-120	1.21	38	42	20	Clay
	mean	1.16				
Tail	0-30	1.11	24	44	33	Clay
	30-60	1.09	22	42	34	Clay
	60-90	1.17	14	42	44	Silt clay
	90-120	1.19	18	28	54	Silt clay loam
	mean	1.14				
Overall mean		1.16	26	42	32	Clay

growth.

3. Results and Discussion

3.1. Soil Physical Properties of Study Scheme

According to the USDA SCS soil textural triangle, the textural class for Woybo irrigation scheme was observed to be clay soil except at 60-90cm and 90-120cm depth of tail canal reach was silt clay and silt clay loam, respectively (Table 1).

The study indicates that average bulk density was 1.16 g/cm³. The study revealed an increasing trend in bulk density with increasing soil depth, suggesting a slightly increase in soil compaction. The results are in line with recommendation by Miller and Donahue [19], which suggests that bulk density below 1.4 g/cm³ for clay soil is necessary for optimal plant

3.1.1. Soil Moisture at FC and PWP

In Woybo irrigation scheme, the study shown that field capacity (FC), permanent wilting point (PWP) and total available water of the soil were varied from 33.5% to 41.24%, 21.9 to 27.2% and 101.5 to 163mm/m with average values of 37.18%, 23.43% and 135.73mm/m, respectively (Table 2).

According to FAO [6] recommendation the values of FC, PWP and TAW at scheme's soil were within the acceptable ranges for clay soil ranges from 320-400 mm/m, 200-240 mm/m and 120-200 mm/m, respectively. But, an average water holding capacity of soil at scheme was low.

Table 2. Selected Soil FC, PWP and TAW.

Location	Soil depth (cm)	Soil physical properties (v/v), %		TAW (%) (v/v)	TAW (mm)
		θ_{FC}	θ_{PWP}		
Head	0-30	41.24	27.2	14.04	42.12
	30-60	36.16	24.7	11.46	34.38
	60-90	38.7	24.5	10.15	30.45
	90-120	37.1	22.3	14.8	44.4
	Total				151.35
Middle	0-30	37.0	23.2	13.8	41.4
	30-60	37.7	23.0	14.7	44.1
	60-90	35.1	22.3	12.8	38.4
	90-120	36.8	23.2	13.6	40.8
	Total				164.7
Tail	0-30	39.1	22.8	16.3	48.9
	30-60	37.1	22.3	14.8	44.4
	60-90	36.65	23.8	12.85	38.55
	90-120	33.5	21.9	11.6	34.8
	Total				166.65
Overall mean value					160.9

3.1.2. Soil Infiltration Rate

As study indicated that the average measured value of the basic infiltration rate for three selected canal reaches of farmer's fields was 7.2 mm/hr attained after elapse of 178 minutes. The study shows that the value was slightly higher than recommended by Savva and Franken, which is 1-5mm/hr for clay soil [20].

3.2. Conveyance Water Delivery Efficiency

In Woybo irrigation scheme, the average conveyance efficiency and water loss per 100m in the main canal system were 83.38% and 4.05 l/s, respectively (Table 3). It implies that the average of 16.62% of water was lost from the main canal before reaching the secondary canal. Besides, an average conveyance efficiency of secondary canal was 72.92%, with a water loss of 3.18 l/sec per 100m of the canal.

The results indicate that the overall conveyance efficiency of the Woybo irrigation scheme was 60.8%. This means that 39.2% of the diverted water was lost before it reaches to the to the farm inlets. The current result was below than that of recommended by FAO for earthen canal length greater than 2000 meters in clay soil, which is 80% [6].

The main causes for poor conveyance efficiency at there were high leakage, silt deposition, overtopping due to silt accumulation, weed growth, malfunctioning gates and increased of illegal users. This inefficient irrigation water delivery affected the equity of water distribution throughout systems; mostly the tail end users did not receive their equitable share within the required time at Woybo.

Nearly similar finding was reported by Muhammedziyad, overall conveyance efficiency of Gemesha irrigation scheme was 61.1% [21].

Table 3. Conveyance efficiencies and water loss.

Canal section	Conveyance efficiency,%	Water Loss,%	Water loss (l/s) /100m
Main canals	83.38	16.62	4.05
Secondary canals	72.92	27.08	3.18
Scheme efficiency,%	60.80		

3.3. On-farm Water Management Performance

3.3.1. Application Efficiency

The application efficiencies of scheme were 46.51, 47.68 and 51.41% for head, middle and tail end water users' fields, respectively (Table 4). The result indicates that tail end water user is better than at the head and middle of the scheme. The tail users were better in effective utilization available water due to water scarcity at tail canal reaches.

The study revealed that average application efficiency was

found to be 48.53% for scheme. The application efficiency of Woybo scheme was below the acceptable range (50-70%) for properly designed furrow irrigation according to Savva and Franken [20]. The major reasons for weakness of on-farm water management are knowledge limitation on irrigation scheduling and water management on the field by farmers.

Similar finding was reported by Henok and Kedir which was 48.2% for Wosha irrigation scheme [22]. Likewise, nearly similar finding was reported by Ayele which was 49.7% for application efficiency for Guder irrigation scheme [23].

Table 4. Application efficiencies.

Field location	Applied depth (mm)	Stored water (mm)	Efficiency (Ea, %)
Head	130.88	60.87	46.51
Middle	106.84	50.94	47.68
Tail	114.47	58.85	51.41
Scheme efficiency (%)			48.53

3.3.2. Storage Efficiency

The result shown, water storage efficiency was varies from 91.61% at head to 78.05% at the tail end water users' field (Table 5). The highest storage efficiency was recorded in the head and lowest storage efficiency was recorded at tail end.

The current finding for Woybo scheme was 85.22% of the soil moisture deficit was adequately satisfied for productivity

of the crops. However, the result was slightly below the recommended value which is 87.5% according to Natural Resource Conservation Service of UK for a homogenous soil condition [24]. Therefore, farmers should improve on farm water conservation techniques through introducing soil mulching practice.

Table 5. Storage efficiencies.

Field location	Stored water (mm)	Required water (mm)	Storage efficiency (Es, %)
Head	60.87	66.44	91.61
Middle	50.94	59.23	86.00
Tail	58.85	75.4	78.05
Scheme Storage Efficiency (Es, %)			85.22

3.3.3. Water Distribution Uniformity

A study indicates that the average distribution uniformity of Woybo was found to be 84.56% (Table 6). The result showed that there was higher distribution uniformity at tail field users than head and middle fields. According to Imark, a value low

DU (<60%) indicates that water is unevenly distributed, while a high DU (>80%) indicates that the application is relatively uniform across the entire field [17]. Therefore, the farmers' practice of water distribution uniformity over the entire fields at the Woybo scheme was found to be adequate.

Table 6. Water distribution uniformity.

Field location	Mean stored water (mm)	Least quarter mean stored water (mm)	DU, %
Head	59.21	50.08	84.58
Middle	58.27	48.6	83.4
Tail	52.51	45.0	85.7
Scheme DU (%)			84.56

3.3.4. Deep Percolation Ratio

The study revealed that the average deep percolation loss of scheme was found to be 51.47% (Table 7). This implies that about 51.47% of the applied water was lost from the total depth of water applied.

The highest loss was observed at head and middle field users, with 53.50 and 52.33% of the applied water, respectively. The lowest deep percolation loss was recorded at the

tail of the scheme, at 48.59%. The results indicate that majority of farmers commonly used closed-ended furrows. However, farmers experienced low application efficiencies due to irrigating more water without considering the water requirement.

Nearly similar finding was reported by Henoke and Kedir, where the average scheme deep percolation loss for the Wosha scheme was found to be 51.8% [22].

Table 7. Deep percolation ratio.

Field location	Application Efficiency, %	Runoff ratio, %	DPR (%)
Head	46.50	0	53.50
Middle	47.67	0	52.33
Tail	51.41	0	48.59
Scheme efficiency	48.53		51.47

3.4. Overall Scheme Efficiency

The study shown, that the overall efficiency of Woybo scheme was 29.53%. The result indicates that scheme was below acceptable a range (40-50%) was reported in other similar African irrigation schemes by Savva and Frenken [20]. The current finding shows that scheme was performing in poorly manner. This was resulted as the reason of high water losses in delivery system and poor on-farm water management practices at Woybo scheme. Nearly similar finding was reported by Shiberu, which was 28.59% at Dodicha irrigation scheme [25].

Table 8. Overall efficiencies of Woybo scheme.

Internal indicators	Efficiency (%)
Conveyance efficiency	60.85

Internal indicators	Efficiency (%)
Application efficiency	48.53
Storage efficiency	85.22
Distribution efficiency	84.56
Deep Percolation ratio	51.47
Overall efficiency	29.53

4. Conclusions

The study findings showed that the overall efficiency of the Woybo scheme was 29.53%. This indicates a relatively low efficiency of water delivery and utilization within the scheme. As the result of inadequate water distribution and various defects at the main canal, such as fractured sections of the canal, damaged division boxes, siltation, and maintenance issues, contributed to the low water delivery efficiency. Poor

water management and significant water losses from deep percolation during irrigation events were the main causes of low application efficiency. However, uniformity of the water distribution and the efficiency of the water storage were reasonably good.

Based on these findings, the following suggestions are made: Farmers water management should be supported by appropriate irrigation scheduling, training on water application techniques, using surge irrigation techniques, mulching, and water conserving are recommended to improve the water use efficiency. In order to increase the performance of water delivery, it suggested to maintain, and repair broken division boxes and regulating gates or lining earthen canal section in addition to regularly cleaning of the earthen canal. The water users committee should be strengthened by training and there should be monitoring and evaluation by respected bodies to ensure continuous improvement of irrigation system.

Author Contributions

Serawit Gensa: Conceptualization, Data curation, Software, Formal Analysis, Investigation, Writing - original draft, Methodology, Visualization, Writing - review & editing

Abraham Woldemichael: Conceptualization, Supervision, Writing - review & editing

Moltot Zewdie: Conceptualization, Supervision, Writing - review & editing

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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