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Research Article

Performance Evaluation of Dorso Irrigation Scheme at Abaya Distrcit, West Guji Zone, Oromia Region, Ethiopia

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Abstract

Many irrigation schemes are performing poorly for a number of reasons, and should be improved to increase the efficiency and productivity of the schemes. This study attempted to determine the performance of Dorso irrigation scheme in Abaya District. For field data measurements, three farmers' fields were selected at upper, middle, and lower scheme. The internal performance indicators, Agricultural Performance Indicators and physical performance indicators were used for data analysis. From internal indicators, the average conveyance efficiency of lined and unlined main canal were 91.11% and 78.04%, with a mean conveyance loss 0.0190 l/s and 0.0210 l/s. The application efficiency of the scheme were 48.64%, 42.05%, and 48.91% at head, middle, and tail reach, with average application efficiency of 45.53%. The storage efficiency (Es) of scheme at upper, middle and tail user of the scheme were 54.53%, 58.39%, and 41.72%, respectively, with average of 51.55%. This implied the scheme was performing inefficiently. The estimated water distribution uniformity of the scheme were 93.28%, 90.30%, and 97.31% at head, middle, and tail reach, with an average of 93.63%. The water deep percolation ratio computed in the selected fields at three were, 51.36%, 57.95%, and 51.09%, with the average of 53.47%. As internal performance indicators show, the overall efficiency of the Dorso irrigation scheme was 28.88%. The Agricultural Performance Indicators used and the total crop productivity of 889,095 kg was obtained from crop area of 61 ha and total gross income 331076.72 $. The performance indicator with respect to land and water productivity shows, the output per unit irrigated and command area were 7197.32 and 3310.77 US$/ha. The output per unit irrigated area is better than output per unit command area. The output per irrigation supply and water consumed during 2023/24 irrigation season were 1.91 and 1.51 US$/m^3. The result of output per water consumed was out of the recommended range. The calculated relative water supply was 0.79. The total water supplied was insufficient for the water demand of crop. The computed relative irrigation supply was 0.31, the diverted irrigation supply was insufficient for irrigation demand. The irrigation ratio of the scheme was 0.61, means 61% of the command area was currently under irrigation and 39% was not during study period. The scheme's sustainability value for irrigated area was 0.61, suggests irrigated area contraction and less sustainable than initially. So, adopting the best practices and awareness creation of irrigation scheme users are very important.

Keywords

Efficiency, Irrigation Scheme, External and Internal Indicators, Overall Scheme, Performance, Productivity, Profitability

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1. Introduction

Water is the most limited resource, which is widely used by different sectors like agriculture, water supply, and industrial. Due to the rapid increase in the world population, food demand also increased as well. The competition for this scarce resource is increasing from time to time due to increasing food demand from the highly consuming agricultural sector [1, 2].

According to FAO (2011) report, irrigated agriculture is the most inefficient and much water consuming sector, which contributes globally about 70% of water withdrawal from different sources like aquifers, streams, and lakes and it is over 90% in most of the least developed countries. Without improved efficiency measures, agricultural water consumption is expected to increase by about 20% globally by 2050 [3].

Performance evaluation is a practical tool to assess the successes of irrigation management at the scheme to meet growing challenges; increasing demand for irrigation to meet the growing food demands of the population: the competition for water allocation from high priority non-agricultural sectors and technical infeasibility [4]. It is necessary to retrofit new techniques and approaches to existing management practices to improve the performance of the scheme. In recognition to both the promise and hazards associated with irrigation, evaluating irrigation performance has now become of para-mount importance not only to point out where the problem exists but also helps to identify alternatives that may be both effective and feasible in improving system performance [5].

Performance of most irrigation schemes is significantly below their potential. A large part of low performance may be due to inadequate water management at system and field level [6]. This includes low-cost recovery and low water use efficiencies induced by area-based water allocation and poor water delivery performance. Not only efficiency, but also the sustainability of the irrigation schemes is in question.

There are no significant studies regarding performance evaluation of small-scale irrigation schemes in the study area. Dorso small-scale irrigation scheme was operated and managed by the water users with involvement of government agencies. Even though this irrigation scheme is a functional scheme but the performance was not evaluated. Thus, evaluation of the performance of this irrigation scheme is very crucial to identify the factors that promote and inhibit the performance which can be assessed against key indicators.

Therefore, the study aimed to investigate and evaluate the performance of irrigation system of Dorso small scale irrigation scheme. The evaluation of the performance of this small-scale irrigation system was carried out clearly identify the main cause of the performance evaluation and other related problems and to forward the output of the evaluation.

2. Materials and Methods

2.1. Description of the Study Area

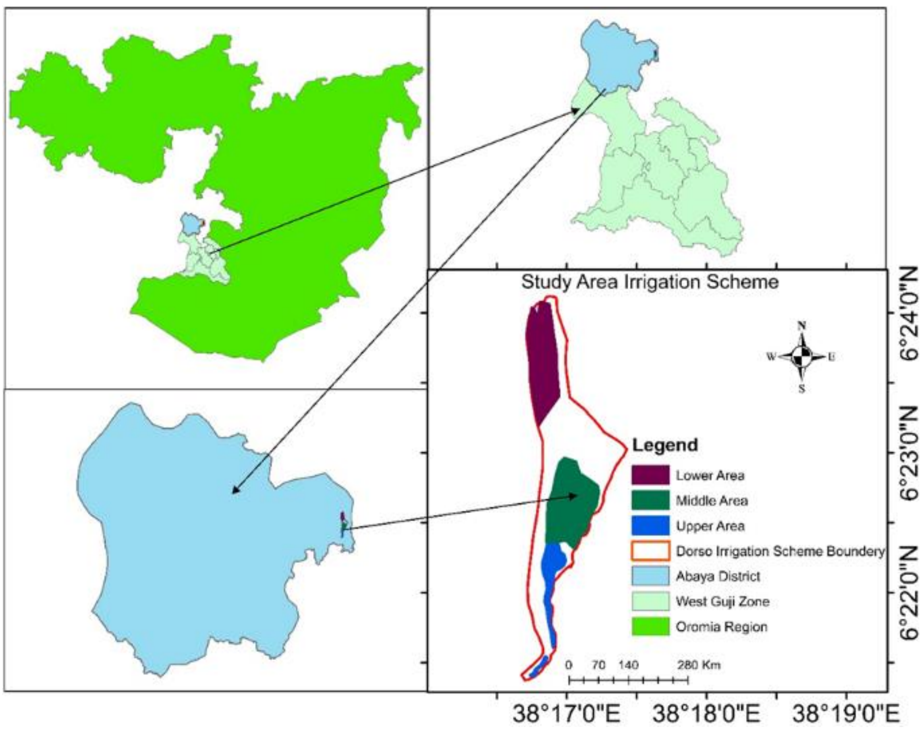

Figure 1. Map the study area.

Dorso irrigation scheme is located in Abaya District, west Guji zone of the Oromia Region. It was designed to irrigate 100 ha of land but now it irrigates only 61 ha of land during the study period. The current irrigable area of the scheme is 70 ha with a total of 194 house hold using the scheme. The most widely cultivated crops in the schemes are maize, tomato, cabbage; Coffee, Banana, onion, local cabbage, sweet potato, common bean, wheat and Sugar cane. During this study the command area of the scheme was dominated by maize crop. The scheme is located 9km from the North side of Guangua town. The watershed of this area was part of Genale Dawa Basin. It was geographically located from 6°2'00" to 6°24'00" N and 38°17'00" to 38°19'00" E longitude with an elevation of 1557 m.a.s.l. Long-term climatic record of nearby meteorological station showed an average minimum and maximum temperature of 10.3 and 24.7°C respectively. The scheme receives a mean annual rainfall of 1167.4 mm with maximum rainfall on month of April, May, September and October.

2.2. Methodology

The study was done by collecting secondary data like design documents, operational manuals and any valuable information from previous studies and field data collection on parameters was used for irrigation performance studies.

Preliminary data like boundary of the scheme/geographic location, altitude, agro climatic condition, water source, soil data (physical and chemical parameters), meteorological and crop data (crop type, sowing & harvest date, length of growth period, root depth, crop coefficient, optimum depletion level were collected.

Then schemes performance assessment work were done following standard procedures using the performance indicators. These performance indicators broadly categorized into internal and external indicators [7].

2.2.1. Field Layout and Crop Selection

To evaluate the irrigation application, deep percolation ratio, storage and distribution uniformity three farmers' fields were 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 were done considering willingness of the farmers to collaborate. The dominant crops, which was the most of the scheme land covered with it, was used as testing crop. The amount of water irrigated at head, middle and tail reach were measured by three inch parshal flume.

2.2.2. Internal Indicators

For this 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 application efficiency, storage efficiency, deep percolation ratio and distribution uniformity were evaluated.

2.2.3. Conveyance Efficiency (Ec)

To determine the conveyance efficiency, the flow discharge at main and secondary canals at hundred-meter interval was recorded using area velocity method. Lined and unlined canal were measured separately. The velocity was measured by floating methods; the discharges was calculated from the canals cross-sectional area and measured velocities.

2.2.4. Procedure

For accurate measurement straight section of canal, having uniform grade with minimum surface agitation were selected. The start and end point of the reach were marked appropriately travel time exceed 20 seconds. Floating material was dropped into the upstream part of the specified place by marker, and recording time was start. When the object crosses the upstream marker and stop the watch when the object crosses the downstream marker. The measurement were repeated three times and the average was used in further calculations (velocity and discharge). The cross-sectional area of the canal was determined by measuring the average depth and width of the canal section.

This procedure was used to estimate the discharge at the upstream (Qin) and downstream end (Qout) of the canal (main, secondary and tertiary).

For the sake of adjustment, the measured velocity was multiplied by correction factor 0.85 for rough or rocky bottoms and 0.90 for smooth, muddy, sandy or smooth bedrock conditions as illustrated by [8]. Harrelson et al. (1994). Finally, the conveyance efficiency was computed using the following equation [9].

$$EC = \frac{Qin}{Qout} * 100$$

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

$$EC = Em * Es * Et$$

Where, Ec (conveyance efficiency%), Em (conveyance efficiency of the main canal%), Es (conveyance efficiency of secondary canal%) and Et (conveyance efficiency of tertiary canal in%).

Losses in conveyance system was computed as;

$$LC = Qin - Qout$$

Where: Lc: conveyance loss (m^3/sec), Qin and Qout: were inflow and outflow of discharge in specified canal length (m^3/sec).

(i). Application Efficiency (Ea)

The application efficiency was computed as the ratio of moisture stored in the soil profile and the total irrigation water applied to the field. The amount of irrigation water applied to the field was determined using Parshall flume. The depth of water which is stored in the root zone of the soil was determined by collecting soil samples at different depths (0-30, 30-60 and 60-90cm) depending on the crop type growth stage, and one days after irrigation depending on soil type. The moisture content stored in the root zone was determined by a gravimetric method using the following equation.

$$\theta V = \frac{Ww - Wd}{Wd - Wc} * \frac{Pb}{pw} * 100$$

Where: θv: volumetric water content (%); Ww: weight of wet soil (g); Wd: weight of oven dried soil (g); wc: weight of container (g); ρb: soil bulk density (g/cm^3); ρw: density of water (g/cm^3).

The soil sample was collected from three representative sites of the selected farm of the scheme; five sample were collected, four sample from the two diagonal line point of the middle from center point to the edge and one sample from the intersection line of both (center) of the farm area.

$$ws = \frac{\theta v \times d}{100}$$

$$Wf = \frac{Q \times t}{A}$$

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 [9].

$$\mathrm{Ea} = \frac{\mathrm{Ws}}{\mathrm{Wf}} * 00$$

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).

(ii). Storage Efficiency (Es)

To determine the water stored in the soil root zone of each field, soil samples was collected from a different location within the field (The soil sample was collected from three representative sites of the selected farm; five sample was collected. The distribution uniformity was obtained by the relationship given below [9].

$$Es = \frac{\mathrm{Ws}}{\mathrm{Wn}} * 100$$

Where: - Es: storage efficiency (%); Ws: water stored in the root zone during irrigation (mm) calculated using moisture content determination method as above; Wn: water needed in the root zone prior to irrigation.

The water needed in the root zone prior to irrigation was computed using the following equation [9].

$$Wn = \sum_{i=1}^{n} \frac{\mathrm{Mfci} - \mathrm{Mbi}}{100} * \frac{\rho \mathrm{b}}{\rho \mathrm{w}} * di$$

Where: - Wn: net amount of water to be 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 ith 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.

(iii). Water Distribution Uniformity (DU)

The water distribution uniformity indicates the extent to which water is uniformly distributed in the field. The water distribution was computed using equation given by [10]. To determine the water stored in the soil root zone at each field was divided into three parts at the head, middle, and tail of the field. Totally, from five places at a depth of the 0-30, 30-60 and 60-90 of soil sample was collected before and after each irrigation event. Then after soil moisture contents of the soil samples determined gravimetrically, at the selected points, the depth of stored water at particular soil layer (X (0-30) or X (30-60)) was calculated using the equation:

$$X = \left(\frac{\mathrm{Mai} - \mathrm{Mbi}}{100}\right) * \frac{Pb}{pw} * di$$

Where: - X: soil moisture content stored at a particular point (mm); Mai: & Mbi: moisture content of the ith 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 ith layer (mm). The total depth of water stored at each point (X1 to X4) was determined, by sum up the values of X1(0-30), X1(30-60) and X1(60-90) of that specific point.

X1 = X1(0-30) + X1(30-60) + X1(60-90) to X4 = X4(0-30) + X4(30-60) + X4(60-90)

Then finally, the distribution uniformity was determined using equation.

$$DU = \frac{\bar{X}lq}{\bar{X}m} * 100$$

Where: - Du: Water distribution uniformity (%); $\bar{X}$ Lq: the mean of lower-quarter depth of water infiltrated (mm); $\bar{X}$m: the mean depth of all water infiltrated caught in (mm).

Deep Percolation Ratio

The deep percolation ratio was calculated by using the following equation [11].

$$DPR = 100 - Ea - RR$$

Where: - DPR: Deep percolation ratio (%); Ea: application efficiency (%); RR: runoff ratio (%), then the overall scheme efficiency was calculated as the product of conveyance and application efficiency [12]:

$$EP = EC * Ea$$

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

(iv). External Indicator

For the study nine external indicators were used as illustrated by International Water Management Institute [7].

(v). Agricultural Output Indicators

To determine the external indicators of the selected scheme such as output per cropped area, output per unit command area, and output per unit water consumed; crop production data, irrigable-cropped area and command area was collected from each District Agricultural Office. Total production (US$) for the study year was calculated by using local farm gate price and each crop yield production of the selected irrigation scheme. The amount of diverted water at intake of the schemes was measured. The following equations was used to compute agricultural output indicators [7]. It includes four basic comparative indicators listed below:

$$\text{Output per unit irrigated area} \left(\frac{\$}{ha}\right) = \frac{Production}{irrigated\ cropped\ area}$$

$$\text{Output per unit command} \left(\frac{\$}{ha}\right) = \frac{Production}{Command\ area}$$

$$\text{Output per unit irrigation diverted} \left(\frac{\$}{m^3}\right) = \frac{Production}{Irrigation\ diverted}$$

$$\text{Output per unit water consumed} \left(\frac{\$}{m^3}\right) = \frac{Production}{Volume\ of\ waterconsumed\ by\ ET}$$

(vi). Water Supply Indicators

Relative irrigation and relative water supply for the selected irrigation schemes was evaluated for the growing period. Irrigation supply the volume of irrigation water delivered from the water source, was measured at the head works of each schemes. Relative water supply was the sum of delivered irrigation water and effective rainfall. Total crop water demand the actual evapotranspiration demand of the crops, was determined using CROPWAT 8.0 computer model for a given cropping pattern and irrigation intensity.

The crop requirement was calculated for each month using the following equation for different crops.

$$CWRmonthly = CWR1 * \left(\frac{area\ 1}{area\ total}\right) + CWR2 * \left(\frac{area\ 2}{area\ total}\right) + CWR3 * \left(\frac{area3}{area\ total}\right)$$

$$IWD = CWR\ (m3) - Peff(m^3)$$

$$IWS = DIW\ (m3) + Peff(m^3)$$

Both relative water supply and irrigation supply was determined using the following equation [7].

$$RIS = \frac{\text{IWS}(m^3)}{IWD(m^3)}$$

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).

(vii). Water Delivery Capacity Indicator (WDC)

The water delivery capacity was computed from the design discharge capacity taken from the design document of the selected irrigation scheme. However, if the design document of some irrigation scheme may not be available, the main offtake canal capacity was computed from the canal structure cross-section at the diversion intake by measuring the area, velocity and freeboard was considered. The peak monthly demand was computed by CROPWAT 8.0 model. And was calculated using equation recommended by [13].

$$WDC = \frac{Canal\ capacity\ to\ deliver\ water\ at\ system\ head}{Peak\ cosumptive\ demand}$$

(viii). Physical Indicators

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 [7].

(ix). Irrigation Ratio (IR)

It 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 [14].

Irrigation ratio is the ratio of currently irrigated area to the command area [12].

$$IR = \frac{Irrigated\ cropped\ area}{Command\ area}$$

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.

(x). Sustainability of Irrigated Area (SIA)

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 selected scheme was determined from each district Agricultural office. Sustainability of irrigated area was computed by using the following equation [7].

$$SIA = \frac{Currently\ Irrigable\ area}{Initially\ Irrigated\ area}$$

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

2.2.5. Economic and Financial Indicators

(i). Gross Return on Investment

When assessing financial performance, financial outlays was compared with the original cost tables and budgets to examine whether the financial targets originally agreed upon have been fulfilled and whether in general the financial control was satisfactory.

Cost of water, hiring security guard, Cost of repairs and servicing of equipment, canals and structures, Cost of inputs, for example: seed, fertilizer, chemicals, transport; Prices of production;

Marketing costs, for example packaging; Access to credit; source, interest rates, etc.

$$\text{Gross reture on investment (\%)} = \frac{\text{SGVP}}{Cost\ of\ irrigation\ infrastructure}$$

Where: Cost of irrigation infrastructure considers the cost of the irrigation water delivery system referenced to the same year as the SGVP (the standard gross value of production).

(ii). Financial Self Sufficiency

The intention of constructing irrigation infrastructures is to enhance the production and productivity of the beneficiaries, thus this parameter help to evaluate if the economic return is sufficient to invest for operation and maintenance of the scheme.

$$\text{Financial self sufficiency} = \frac{Revenue\ from\ irrigation}{Total\ O\&M\ expenditure}$$

Where: -Revenue from irrigation, is the revenue generated, either from fees, or other locally generated income, and Total O&M expenditures are the amount expended locally through O&M plus outside subsidies from the government.

(iii). Profitability

The intention of constructing irrigation infrastructures is to enhance the production and productivity of the beneficiaries, thus this parameter help to evaluate if the scheme is profitable.

$$\text{Area based profitability} = \frac{Increamental\ benefit\ per\ unit\ area}{Total\ irrigation\ expences}$$

$$\text{Area based profitability} = \frac{Incremental\ benefit\ per\ unit\ water}{Total\ irrigation\ expenses}$$

3. Results and Discussion

3.1. Soil Physical Property Analysis

According to the USDA SCS Soil textural triangle, the textural class for Dorso irrigation scheme was sandy clay, clay loam, loam, sandy clay loam and sandy loam which clay loam was relatively dominant. The average bulk density of the sampled properties of the soil results was at the head, middle, and tail reach of the canal which were 1.46, 1.47, and 1.43 g/cm^3, respectively (Table 1).

Table 1. Laboratory result of soil physical property of the Dorso irrigation scheme.

Scheme Command	Depth (cm)	Percentages (%) of			Soil Textural class	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm)
		Sand	Clay	Silt					
	0-30	46.39	34.77	18.84	Sandy clay	1.48	37.10	26.00	49.28
Upper	30-60	36.82	36.73	26.44	Clay loam	1.40	35.00	21.30	57.54
	60-90	47.88	27.09	25.03	Sandy clay loam	1.51	28.30	18.30	45.30
	0-30	47.26	22.72	30.02	Loam	1.44	26.70	12.60	60.91
Middle	30-60	55.74	19.70	24.56	Sandy loam	1.46	17.90	8.10	42.92
	60-90	56.65	20.87	22.48	Sandy clay loam	1.51	28.30	18.30	45.30
	0-30	44.40	31.05	24.55	Clay loam	1.40	35.00	21.30	57.54
Lower	30-60	47.74	37.20	15.06	Sandy clay	1.48	37.10	26.00	49.28
	60-90	44.15	38.35	17.49	Clay loam	1.40	35.00	21.30	57.54

Scheme Command	Depth (cm)	Percentages (%) of			Soil Textural class	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm)
		Sand	Clay	Silt					
Overall average		47.45	29.83	22.72	Sandy clay loam	1.51	28.30	18.30	51.74

3.2. Crop and Irrigation Water Requirements

Crop water and irrigation water requirements were calculated using CROPWAT 8.0 model by using crop characteristics and soil data as input for the major irrigated crops grown in the irrigation schemes as in (Table 2) and used as input for irrigation water delivery performance indicator (Table 3).

Table 2. The major seasonal irrigated crops were grown in the irrigation scheme.

Crop type	Effective rainfall mm/season	Crop water requirement mm/season	Irrigation requirement mm/season
Maize	296	442.4	202.3
Wheat	724.0	816.7	187.5
Onion	150.5	367.6	218.6
Hot-pepper	296	457.4	187.6
Head Cabbage	663.1	779.5	177.1
Beet root	150.5	367.6	218.6
Carrot	150.5	367.6	218.6

3.3. Internal Performance Indicators

3.3.1. Conveyance Efficiency

The results of the conveyance efficiency evaluation revealed different value at different canal length of Dorso irrigation scheme. Based on the result of this study the average conveyance efficiency of lined and unlined main canal were 91.11% with a mean conveyance loss of 0.0190 l/s and 78.04% with a mean conveyance loss of 0.0210 l/s respectively. Moreover, under both lined and unlined main canal of Dorso scheme showed a tendency of decreased conveyance efficiency and increased conveyance loss as the distance of canal increase from inlet discharge at canal length of 100 m to 1800 m and 100 to 669 m respectively (Tables 3 and 4). According to [15], reports, the conveyance efficiency for unlined canal could be 80 and 95% for the lined canal; therefore, both unlined and lined canals of the Dorso irrigation scheme were not in the range of recommended efficiency.

The main reason conveyance efficiency losses in main canal of Dorso irrigation scheme was due to none functionality of offtakes, sedimentation, seepage of the canal, illegal use of water like for wash purposes, stealing offtake metal sheets and illegal water diversion by creating offtakes not included in design in each head, middle and tail users.

Table 3. Conveyance efficiency for lined main canal of Dorso irrigation Scheme.

Canal Length (m)	Flow length (m)	Time (sec)			Average time (sec)	Corrected Velocity (m/sec)	Area (m^2)	Discharge (m^3/s)	Conveyance efficiency of each length (%)	△Q/Lt (m^3/sec/m)
		T1	T2	T3						
0	10	21.27	20.08	17.43	19.59	0.434	0.459	0.199124		
100	10	14.01	18.2	16.13	16.11	0.528	0.3696	0.194969	97.91	0.0415
200	10	17.32	16.47	16.4	16.73	0.508	0.3822	0.194184	97.52	0.0247

Canal Length (m)	Flow length (m)	Time (sec)			Average time (sec)	Corrected Velocity (m/sec)	Area (m^2)	Discharge (m^3/s)	Conveyance efficiency of each length (%)	△Q/Lt (m^3/sec/m)
		T1	T2	T3						
300	10	17.98	16.97	17.96	17.64	0.482	0.4028	0.19413	97.49	0.0166
500	10	19.91	20.07	22.23	20.74	0.410	0.4704	0.192818	96.83	0.0126
600	10	18.76	17.98	18.62	18.45	0.461	0.42	0.193461	97.16	0.0094
700	10	17.01	19.9	18.54	18.48	0.460	0.41	0.188548	94.69	0.0151
800	10	16.26	17.1	16.62	16.66	0.510	0.38	0.193878	97.37	0.0066
900	10	19.12	18.39	18.12	18.54	0.458	0.43	0.197106	98.99	0.0022
1000	10	19.22	20.29	20	19.84	0.428	0.395	0.169257	85.00	0.0299
1100	10	17.65	17.88	18.15	17.89	0.475	0.3476	0.165123	82.92	0.0309
1200	10	16.2	16.5	17.47	16.72	0.508	0.3854	0.195888	98.37	0.0027
1300	10	18.84	18.15	20.87	19.29	0.441	0.415	0.182898	91.85	0.0125
1600	10	17.73	20.49	19.68	19.30	0.440	0.376	0.165596	83.16	0.0210
1700	10	15.15	16.49	16.45	16.03	0.530	0.28	0.148472	74.56	0.0298
1800	10	17.37	16.44	16.31	16.71	0.509	0.2849	0.144951	72.79	0.0301
Average									91.11	0.0190

Table 4. Conveyance efficiency for unlined main canal of Dorso irrigation Scheme.

Canal Length (m)	Flow length (m)	Time (sec)			Average time (sec)	Corrected Velocity (m/sec)	Area (m^2)	Discharge (m^3/s)	Conveyance efficiency of each length (%)	△Q/Lt (m^3/sec/m)
		T1	T2	T3						
0	10	31.14	18.12	26	25.09	0.339	0.209	0.070815		
100	10	19.61	21.96	20.8	20.79	0.409	0.161	0.065825	92.95	0.0415
200	10	22.56	12.21	24.12	19.63	0.433	0.1488	0.064432	90.99	0.0247
329	10	12.78	12.21	12.08	12.36	0.688	0.0816	0.056132	79.27	0.0166
429	10	18.79	20.12	21.96	20.29	0.419	0.1088	0.045579	64.36	0.0126
669	10	24	19.83	18.19	20.67	0.411	0.1079	0.044364	62.65	0.0094
Average									78.04	0.0210

3.3.2. Application Efficiency

The estimated application efficiency of Dorso irrigation scheme was 48.64%, 42.05%, and 48.91% at the head, middle, and tail reach, respectively, with an average application efficiency of the scheme 45.53% (Tables 5-7). As [15], reported the average application efficiency for surface irrigation in the range of 50 to 60%. And [16] recommended 50 to 70% for properly designed furrow irrigation. The average values of application efficiencies of the three reaches were not within the ranges indicated reported for surface irrigation.

Table 5. Application efficiency of Dorso irrigation Scheme at Head reach.

Depth (cm)	Sample Number	Ws (mm)	Q (lit/sec)	T (sec)	A (m^2)	Wf (mm)	Ea
0-30	P1 (0-30)	23.61	2.14	3269.05	250.00	27.98	84.38
30-60	P1 (30-60)	4.02	2.14	3269.05	250.00	27.98	14.36
60-90	P1 (60-90)	15.24	2.14	3269.05	250.00	27.98	54.48
0-30	P2 (0-30)	16.08	2.14	3269.05	250.00	27.98	57.45
30-60	P2 (30-60)	9.71	2.14	3269.05	250.00	27.98	34.71
60-90	P2 (60-90)	9.51	2.14	3269.05	250.00	27.98	34.00
0-30	P3 (0-30)	25.38	2.14	3269.05	250.00	27.98	12.40
30-60	P3 (30-60)	10.83	2.14	3269.05	250.00	27.98	36.71
60-90	P3 (60-90)	12.48	2.14	3269.05	250.00	27.98	81.13
0-30	P4 (0-30)	3.47	2.14	3269.05	250.00	27.98	90.69
30-60	P4 (30-60)	10.27	2.14	3269.05	250.00	27.98	38.70
60-90	P4 (60-90)	22.70	2.14	3269.05	250.00	27.98	44.59
0-30	P5 (0-30)	21.26	2.14	3269.05	250.00	27.98	75.97
30-60	P5 (30-60)	6.00	2.14	3269.05	250.00	27.98	21.44
60-90	P5 (60-90)	11.81	2.14	3269.05	250.00	27.98	42.20
Overall Average		13.61	2.14	3269.05	250.00	27.98	48.64

Table 6. *Application efficiency of Dorso Irrigation Scheme at Middle reach.*

Depth (cm)	Sample Number	Ws (mm)	Q (lit/sec)	T (sec)	A (m^2)	Wf (mm)	Ea
0-30	P1 (0-30)	20.03	3.42	1956	246.88	27.10	35.06
30-60	P1 (30-60)	8.68	3.42	1956	246.88	27.10	26.63
60-90	P1 (60-90)	8.20	3.42	1956	246.88	27.10	45.08
0-30	P2 (0-30)	6.46	3.42	1956	246.88	27.10	23.84
30-60	P2 (30-60)	9.37	3.42	1956	246.88	27.10	34.57
60-90	P2 (60-90)	15.86	3.42	1956	246.88	27.10	58.54
0-30	P3 (0-30)	16.87	3.42	1956	246.88	27.10	62.27
30-60	P3 (30-60)	15.60	3.42	1956	246.88	27.10	57.57
60-90	P3 (60-90)	6.06	3.42	1956	246.88	27.10	22.35
0-30	P4 (0-30)	6.15	3.42	1956	246.88	27.10	22.68
30-60	P4 (30-60)	5.73	3.42	1956	246.88	27.10	21.13
60-90	P4 (60-90)	19.77	3.42	1956	246.88	27.10	72.98
0-30	P5 (0-30)	9.50	3.42	1956	246.88	27.10	73.92
30-60	P5 (30-60)	7.22	3.42	1956	246.88	27.10	32.04
60-90	P5 (60-90)	12.22	3.42	1956	246.88	27.10	30.27
Overall Average		11.90	3.42	1956.00	246.88	27.10	42.05

Table 7. *Application efficiency of Dorso Irrigation Scheme at Tail reach.*

Depth (cm)	Sample Number	Ws (mm)	Q (lit/sec)	T (sec)	A (m^2)	Wf (mm)	Ea
0-30	P1 (0-30)	11.78	2.49	2386	283.50	20.96	94.22
30-60	P1 (30-60)	2.10	2.49	2386	283.50	20.96	37.85
60-90	P1 (60-90)	4.28	2.49	2386	283.50	20.96	14.58
0-30	P2 (0-30)	16.75	2.49	2386	283.50	20.96	79.93
30-60	P2 (30-60)	14.97	2.49	2386	283.50	20.96	71.44
60-90	P2 (60-90)	6.62	2.49	2386	283.50	20.96	31.60
0-30	P3 (0-30)	18.35	2.49	2386	283.50	20.96	87.54
30-60	P3 (30-60)	1.88	2.49	2386	283.50	20.96	8.98
60-90	P3 (60-90)	5.17	2.49	2386	283.50	20.96	24.69
0-30	P4 (0-30)	19.75	2.49	2386	283.50	20.96	56.22
30-60	P4 (30-60)	7.93	2.49	2386	283.50	20.96	10.02
60-90	P4 (60-90)	3.06	2.49	2386	283.50	20.96	20.42
0-30	P5 (0-30)	12.11	2.49	2386	283.50	20.96	57.78
30-60	P5 (30-60)	18.75	2.49	2386	283.50	20.96	89.47
60-90	P5 (60-90)	3.40	2.49	2386	283.50	20.96	16.21
Overall Average		10.25	2.49	2386.00	283.50	20.96	48.91

3.3.3. Storage Efficiency

The storage efficiency (Es) of Dorso scheme was determined and analyzed at upper, middle and tail user of the scheme at different depth of the soil. Mean water storage efficiency (Es) computed in the selected fields at the head, middle, and tail-end water users was 54.53%, 58.39%, and 41.72%, respectively, with the average storage efficiency of 51.55% (Tables 8-10). This result implies that the soil moisture deficit of the irrigation scheme satisfied 51.55%. The storage efficiency of the schemes was very poor as compared to 63% storage efficiency usually found in typical furrow irrigation systems [17]. Those were because of mismanagement of water (improper timing and lateral flow into side furrows), soil type and technical failure (Problems with the canal, such as overtopping and seepage, can cause significant water loss).

Table 8. *Storage efficiency computation of the Dorso irrigation scheme at Head Reach.*

No	Location and Soil depth (cm)	Moisture content (%)		FC (%)	PWP (%)	BD	Stored water at each depth (mm)	Required Water	Es (%)
		BI (%)	AI (%)						
1	P1 (0-30)	30.12	35.44	37.1	26	1.48	23.61	31.00	76.17
2	P1 (30-60)	35.72	36.62	37.1	26	1.48	4.02	6.15	65.39
3	P1 (60-90)	30.75	34.12	37.1	26	1.51	15.24	28.76	53.01
Total stored water at RZ							27.63	37.14	74.39
4	P2 (0-30)	31.23	35.17	42	29.9	1.36	16.08	43.94	36.58
5	P2 (30-60)	37.05	39.44	42	29.9	1.36	9.71	20.18	48.14
6	P2 (60-90)	37.37	39.47	42	29.9	1.51	9.51	20.96	45.38
Total stored water at RZ							25.79	64.12	40.22
7	P3 (0-30)	32.29	38.51	42	29.9	1.36	25.38	39.60	64.08

No	Location and Soil depth (cm)	Moisture content (%)		FC (%)	PWP (%)	BD	Stored water at each depth (mm)	Required Water	Es (%)
		BI (%)	AI (%)						
8	P3 (30-60)	38.78	41.44	42	29.9	1.36	10.83	13.12	82.56
9	P3 (60-90)	36.27	39.15	42	29.9	1.44	12.48	24.77	50.37
Total stored water at RZ							36.21	52.72	68.68
10	P4 (0-30)	33.34	34.17	35	21.3	1.4	3.47	6.95	49.90
11	P4 (30-60)	36.94	39.46	42	29.9	1.36	10.27	20.63	49.79
12	P4 (60-90)	36.08	41.64	42	29.9	1.36	22.70	24.17	93.94
Total stored water at RZ							13.74	27.58	49.82
13	P5 (0-30)	34.53	39.45	42	29.9	1.44	21.26	32.25	65.91
14	P5 (30-60)	37.66	39.13	42	29.9	1.36	6.00	17.71	33.86
15	P5 (60-90)	30.13	33.02	42	29.9	1.36	11.81	48.44	24.38
Total stored water at RZ							27.26	49.97	54.55
Overall Average							26.12	46.31	57.53

Table 9. *Storage efficiency computation of the Dorso scheme at Middle Reach.*

No	Location and Soil depth (cm)	Moisture content (%)		FC (%)	PWP (%)	BD	Stored water at each depth (mm)	Required Water	Es (%)
		BI (%)	AI (%)						
1	P1 (0-30)	30.27	34.84	37.1	26	1.46	20.03	29.91	66.96
2	P1 (30-60)	34.52	36.43	37.1	26	1.51	8.68	11.70	74.17
3	P1 (60-90)	36.83	38.84	42	29.9	1.36	8.20	21.09	38.88
Total stored water at RZ							36.91	62.71	58.86
4	P2 (0-30)	32.72	34.20	37.1	26	1.46	6.46	19.18	33.68
5	P2 (30-60)	23.04	25.21	26.7	12.6	1.44	9.37	15.81	59.22
6	P2 (60-90)	35.19	39.08	42	29.9	1.36	15.86	27.78	57.09
Total stored water at RZ							31.69	62.78	50.48
7	P3 (0-30)	34.83	36.23	37.1	26	1.46	6.15	9.94	61.83
8	P3 (30-60)	34.51	35.80	37.1	26	1.48	5.73	11.51	49.76
9	P3 (60-90)	31.38	35.75	37.1	26	1.51	19.77	25.90	76.33
Total stored water at RZ							31.65	47.35	66.83
10	P4 (0-30)	30.60	34.32	37.1	26	1.51	16.87	29.45	57.29
11	P4 (30-60)	32.79	36.24	37.1	26	1.51	15.60	19.51	79.98
12	P4 60-90)	35.19	36.55	37.1	26	1.48	6.06	8.48	71.43
Total stored water at RZ							38.53	57.44	67.08
13	P5 (0-30)	37.88	40.21	42	29.9	1.36	9.50	16.81	56.51
14	P5 (30-60)	34.95	36.58	37.1	26	1.48	7.22	9.53	75.71
15	P5 (60-90)	33.89	36.89	42	29.9	1.36	12.22	33.07	36.94

No	Location and Soil depth (cm)	Moisture content (%)		FC (%)	PWP (%)	BD	Stored water at each depth (mm)	Required Water	Es (%)
		BI (%)	AI (%)						
Total stored water at RZ							28.93	59.41	48.70
Overall Average							33.54	57.94	58.39

Table 10. Storage efficiency computation of the Dorso scheme at Tail Reach.

No	Location and Soil depth (cm)	Moisture content (%)		FC (%)	PWP (%)	BD	Stored water at each depth (mm)	Required Water	Es (%)
		BI (%)	AI (%)						
1	P1 (0-30)	24.05	26.65	28.30	18.3	1.51	11.78	19.26	61.17
2	P1 (30-60)	34.42	34.92	35	21.3	1.40	2.10	2.45	85.49
3	P1 (60-90)	33.98	34.93	35	21.3	1.51	4.28	4.61	92.74
Total stored water at RZ							18.16	26.32	68.97
4	P2 (0-30)	27.74	31.73	35	21.3	1.40	16.75	30.48	54.96
5	P2 (30-60)	25.88	29.25	35	21.3	1.48	14.97	40.49	36.97
6	P2 (60-90)	31.86	33.44	37.10	26	1.40	6.62	22.01	30.08
Total stored water at RZ							38.34	92.99	41.24
7	P3 (0-30)	24.52	28.89	35	21.3	1.40	18.35	44.02	41.68
8	P3 (30-60)	34.76	35.22	42.00	29.9	1.36	1.88	29.53	6.37
9	P3 (60-90)	32.94	34.10	37.10	26	1.48	5.17	18.47	28.01
Total stored water at RZ							25.40	92.02	27.60
10	P4 (0-30)	25.89	30.40	35	21.3	1.46	19.75	39.88	49.51
11	P4 (30-60)	32.74	34.55	35	21.3	1.46	7.93	9.89	80.17
12	P4 (60-90)	32.37	33.10	35	21.3	1.40	3.06	11.04	27.67
Total stored water at RZ							30.73	60.82	50.53
13	P5 (0-30)	23.02	25.90	37.10	26	1.40	12.11	59.14	20.48
14	P5 (30-60)	24.16	25.48	28.30	18.3	1.51	5.95	18.75	31.75
15	P5 (60-90)	22.10	22.85	28.30	18.3	1.51	3.40	28.10	12.09
Total stored water at RZ							21.46	105.99	20.25
Overall Average							26.82	75.63	41.72

3.3.4. Water Distribution Uniformity

The estimated water distribution uniformity of Dorso irrigation scheme were 93.28%, 90.30%, and 97.31% at the head, middle, and tail reach, respectively, with an average water distribution uniformity of the scheme 93.63% (Tables 11-13).

Table 11. Distribution uniformity (Du) at Dorso scheme at Head reach.

D (mm)	ρb/ ρw	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	X5 (mm)
0-300	1.46	23.61	16.08	25.38	3.47	21.26
300-600	1.51	4.02	9.71	10.83	10.27	6.00
600-900	1.36	15.24	9.51	12.48	22.70	11.81
Total depth of water stored at each point		42.87	35.30	48.69	36.44	39.06
Mean of lower quarter $\bar{X}_{Lq}$ (mm)						37.75
Mean Infiltarted water depth $\bar{X}_{m}$ (mm)						40.47
Distribution uniformity (Du) (%)						93.28

Table 12*. Distribution uniformity (Du) at Dorso scheme at Middle reach.*

D (mm)	ρb/ ρw	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	X5 (mm)
0-300	1.46	20.03	6.46	16.87	6.15	9.50
300-600	1.51	8.68	9.37	15.60	5.73	7.22
600-900	1.36	8.20	15.86	6.06	19.77	12.22
Total depth of water stored at each point		36.91	31.69	38.53	31.65	28.93
Mean of lower quarter $\bar{X}_{Lq}$ (mm)						30.29
Mean Infiltarted water depth $\bar{X}_{m}$ (mm)						33.54
Distribution uniformity (Du) (%)						90.30

Table 13*. Distribution uniformity (Du) at Dorso scheme at Tail reach.*

D (mm)	ρb/ ρw	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	X5 (mm)
0-300	1.46	11.78	16.75	18.35	19.75	12.11
300-600	1.51	2.10	14.97	1.88	7.93	5.95
600-900	1.36	4.28	6.62	5.17	3.06	3.40
Total depth of water stored at each point		18.16	38.34	25.40	30.73	21.46
Mean of lower quarter $\bar{X}_{Lq}$ (mm)						26.10
Mean Infiltrated water depth $\bar{X}_{m}$ (mm)						26.82
Distribution uniformity (Du) (%)						97.31

3.3.5. Deep Percolation Ratio

Mean water deep percolation ratio computed in the selected fields at the head, middle, and tail-end water users was 51.36%, 57.95%, and 51.09%, respectively, with the average deep percolation ratio of 53.47% (Table 14).

Table 14. *Deep percolation Ratio (DPR) at Dorso scheme.*

Field Location	Ea (%)	Runoff ratio RR (%)	Deep percolation Ratio (%)
Head Reach	48.64	0	51.36
Middle Reach	42.05	0	57.95
Tail Reach	48.91	0	51.09
Overall Average	46.53		53.47

3.3.6. Overall Irrigation Efficiency of the Scheme

In this study, the overall efficiency of the irrigation scheme was 28.88% which is poor according to [15]; a scheme irrigation efficiency of 50-60% is good, while a scheme irrigation efficiency of below 50% is considered to be poor (Table 15).

Table 15. *Summary of internal process indicators result of Dorso irrigation scheme.*

Internal indicators	Average efficiency of the scheme (%)
Conveyance efficiency	62.07
Application efficiency	46.53
Storage efficiency	52.55
Distribution uniformity	93.63
Deep percolation ratio	53.47
Overall efficiency	28.88

3.3.7. External Performance Indicators

(i). Agricultural Performance Indicators

A total crop productivity of 889,095 kg was obtained at Dorso irrigation scheme from a gross crop area of 61 ha with a total gross income of 331076.72 $ (Table 16). The results of performance indicator with respect to both land and water productivity (output per unit irrigation supply and output per unit water consumed) were indicated in Table 16 below.

Table 16. *Irrigated crop type, yields, and output production values of Dorso irrigation scheme.*

Crop types	Area (ha)	Yield (Ql/ha)	Total yield (Ql)	Unit price (Birr/Ql)	Total output (Birr)	Total income (US$)
Maize	37	206.7	7,647.9	1200	9,177,480	161226.2179
Wheat	3	16	48	6000	288,000	5059.466297
Onion	2.5	90	225	4000	900,000	15810.83218
Hot-pepper	1.5	166.7	250.05	8000	2,000,400	35142.20965
Head Cabbage	2	360	720	9,000	6,480,000	113837.9917
Total	46	839.4	8890.95	28200	18845880	331076.72

Ql = quintal and 1 US$ = 56.923 Ethiopian Birr rate, April, 2024

Table 17. Land and water productivity of Dorso irrigation scheme.

Irrigated area during this study (ha)	Production from total irrigated area (US$)	Designed area (ha)	Total irrigation water applied (m^3 /season)	CWR (m^3/season)	Output per unit irrigated area (US$/ha)	Output per unit command area (US$/ha)	Output per unit irrigation supply (US$/$m^3$)	Output per unit water consumed (US$/$m^3$)
46.00	331076.72	100.00	173189.83	219830.00	7197.32	3310.77	1.91	1.51

According to Table 17, the results of land productivity indicated that the output per unit irrigated and output per unit command area of Dorso irrigation scheme were 7197.32 and 3310.77 US$/ha respectively. The result of this study indicated that the output per unit irrigated area is better than output per unit command area in Dorso irrigation schemes.

The result of water productivity indicated that the output per irrigation supply and water consumed during 2023/24 irrigation season were 1.91 and 1.51 US$/$m^3$ respectively. The result of output per water consumed for Dorso irrigation scheme was out of the recommended range of [7]. Who reported that the output per unit of water consumed for irrigation schemes could be in the range of (0.03-0.91 US$/$m^3$). The reason might be due to good cropping pattern and water use efficiency. A comparable result was reported by [18], at Dirma small-scale irrigation scheme which was 1.64 US$/$m^3$ output per irrigation consumed and 1.25 US$/$m^3$ output per water consumed.

(ii). Water Delivery Capacity Indicator (WDC)

Relative Water Supply: The calculated value of the relative water supply indicator was 0.79. As the result shows, the total water supplied was insufficient for the demand for the crop water. A similar result was reported by [19], at Furfuro irrigation scheme.

Relative Irrigation Supply: The relative irrigation supply (RIS) shows whether the irrigation demand is satisfied or not. The computed value of relative irrigation supply was 0.31 less than one which means that the diverted irrigation supply was insufficient for the irrigation demand of the crop.

Table 18. Relative water supply and relative irrigation supply of Dorso schemes.

Total water applied/season (m^3)	Total net irrigation water applied/season (m^3)	Total CWR/ season (m^3)	Total IR/season (m^3)	RWS	RIS
173189.83	20485.33	219830.00	67125.50	0.79	0.31

CWR= Crop water requirement, IR= irrigation requirement, RWS= relative water supply and RIS relative irrigation supply

(iii). Physical Indicators

Irrigation ratio: The irrigation ratio of the scheme was 0.61 which means 61% of the command area was currently under irrigation and about 39% of the command area was not under irrigation during the study period. The main reasons for this were competition due to lack irrigation schedule irrigation users, the increasing number of water users at upstream of the scheme diversion headwork and unequal share of irrigation at head, middle and tail reaches of the scheme.

Irrigated area sustainability: The scheme's calculated sustainability value for the irrigated area was 0.61 lower than the one, which suggests irrigated area contraction and would mean less sustainable irrigation than what was initially irritated. In other means this implies that the current area under irrigation was decreased by 39% of initially irrigated command area.

Table 19. Irrigation ratio and sustainability of irrigated area for Dorso irrigation scheme.

Currently irrigated area (ha)	Actual irrigated land in any season (ha)	Designed area (ha)	Irrigation ratio	Sustainability of irrigated area
61	70	100	0.61	0.70

4. Conclusion and Recommendation

The performance study of Dorso irrigation were done using the internal, external and physical performance indicators. Internal performance indicators such as conveyance efficiency, field application efficiency, deep percolation ratio, and overall efficiency of the scheme were computed. The average conveyance efficiency was 62.07%. The average field application efficiencies of was 51.58% which is good as compared with an application efficiency of 50-70% for furrow irrigation observed in other African countries. The overall efficiency of the scheme was 28.88% which was poor. These were because of high water loss due to sedimentation and silting with soil of the canal at some places, seepage problem, lack of frequent canal cleaning and maintenance, of-take metal sheet lose and none functionality of it at some places, unauthorized water turnouts (diversion), wild flooding, over irrigation at upper and middle of the canal and illegal water abstractions for washing clothes, Lack of timely monitoring and follow up of the scheme. The study revealed that the overall performance of Dorso irrigation scheme has performing in poor efficiency.

5. Recommendation

The Ways to improve the performance efficiency of the scheme are Continues monitoring, follow up and maintaining the canal bed and wall at cracked places, capacity building of the users and water user association by training farmers on proper water management practices, such as adjusting flow rates and cutoff times, adequate operation and maintenance of the system, control of wild flooding (over irrigation), Making the canal free from the weed, well cleaning and providing the flow control measurement structures at of-take lost are required to recover the irrigation performance of the scheme.

Abbreviations

AF	After Irrigation
BF	Before Irrigation
BD	Bulk Density
CWR	Crop Water Requirement
Ea	Application Efficiency
ETB	Ethiopian Birr
FC	Field Capacity
IR	Irrigation Requirement
RIS	Relative Irrigation Supply
RWP	Relative Water Supply
O&M	Operation and Maintenance
PWP	Permanent Wilting Point
SGVP	Standard Growth Value of Production
TAW	Total Available Water
US$	United States Dollar

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Author Contributions

Obsa Welde Dilgasa: Conceptualization, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing

Tesfaye Gragn Debele: Data curation, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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