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Performance evaluation of the Bilate and Furfuro irrigation schemes in Silti Zone, southern Ethiopia

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Abstract

Many irrigation schemes are performing poorly for a number of reasons, and this should be improved to increase the efficiency and productivity of the schemes. This study attempted to determine the performance of the Bilate and Furfuro irrigation schemes in Silti Zone, southern Ethiopia. For field data measurements, three farmers' fields were selected at the head, middle, and tail end of each scheme. Average conveyance efficiencies were 53% and 56.1%, average field application efficiencies were 55.9% and 58.0%, average water storage efficiencies were 53% and 46.5%, irrigation uniformity was 91.03% and 92.9%, and overall irrigation efficiency was 28% and 32% for Bilate and Furfuro schemes respectively. This implied that the two schemes were performing inefficiently and inadequately, but water was distributed uniformly. The reason might be most canal sections had unreasonable losses of water in two schemes. Additionally, relative water supply was 0.68 and 0.79, relative irrigation supply was 0.61 and 0.77, output per unit irrigated area was 4140.4 and 1781.5 ($/ha), output per unit command area was 4510.3 and 1968.5 ($/ha), output per unit irrigation supply was 0.94 and 0.28 ($\$/m^3$), output per unit water consumed was 0.99 and 0.39 ($\$/m^3$), sustainability of irrigation area was 1.05 and 1.02, and irritation ratio was 1.11 and 1.09 for Bilate and Furfuro schemes respectively. This revealed that the applied water was not satisfied the crop water demand, but their irrigated lands were expanded for two irrigation schemes. Furfuro scheme was better than Bilate in terms of relative water supply and relative irrigation supply, but their results obtained were below acceptable values. However, Bilate scheme had significantly better land and water productivity than Furfuro scheme. This may be use high value crops, better agricultural inputs, and removal of grass cover and sedimentation from canal systems. Hence, Bilate irrigation scheme was better performing than Furfuro scheme. Therefore, adopt the best practices learned from Bilate irrigation scheme for the Furfuro scheme.

Keywords: Performance, Productivity, Efficiency, Irrigation and scheme

Introduction

For many people, agriculture is the foundation of their economic growth in developing countries [18]. Thus, proper utilization and effective use of available water resources in the agricultural sector have a major role in food security and economic development.

In another word, improving agricultural water management and coordinate water with nutrition is one of essential strategies in key food system actors [6, 17]. Accordingly, the expansion of irrigated agriculture on various scales and options, particularly small-scale irrigation schemes, is suggested as the best alternative to provide a positive and significant impact to ensure sustainable agricultural crop production and household income and enhance reliable household food security, social needs fulfillment, and social poverty reduction [9, 22].

Although, in the major outlined in the major part of Ethiopian, irrigated agricultures are served by the surface canal irrigation system. Unfortunately, the majority of operational irrigation schemes are characterized as poor performance level [2, 3, 10, 33]. The performance of the existing irrigation schemes in Ethiopia was estimated at an average of 36% below design capacity. This indicated that about 230,000 ha of irrigated land was lost due to the underperformance of the existing irrigation systems. Almost 90% of these irrigation performance gaps have happened in small-scale irrigation schemes.

Accordingly, any irrigation system must be continuously quantified and monitored concerning crop yield, land, and water productivity as the final goal of the irrigation system [2, 24]. Moreover, the current information on irrigation efficiency, uniformity, adequacy, irrigated agricultural outputs, and continuousness inhibits the improvement of the existing irrigation projects. The field-level irrigation schemes' performance evaluation should consider only inputs (i.e., water).

Bilate and Furfuro irrigation schemes faced various problems like malfunctioned division boxes and flow control gates in canal systems, sedimentation in the main and secondary canal and headwork site, unnecessary grass cover and stagnation of irrigation water in the tertiary canals, poor operation and maintenance practices, lack of awareness of water user and even agricultural experts on crop water demand and irrigation scheduling, high field water competition, lack of irrigation water measurement practice, and poor on-farm irrigation water management strategies. Moreover, the interest of farmers in irrigation has intensified in recent years, increasing water demands, and so, there has been an increasing pressure to improve two irrigation schemes' performance to ensure the land and water productivity.

Furthermore, clear information has been needed on how well one system is performing relative to another, which system responds better to irrigated agriculture output, and how much the irrigation schemes meet the planned and implemented objectives. Unfortunately, no formal and systematic field studies have yet been conducted, and improvement strategies have not yet been recommended for Bilate and Furfuro irrigation schemes. Therefore, this study attempted to evaluate the Bilate and Furfuro irrigation schemes found in Silte Zone, southern Ethiopia, using internal and external performance indicators.

The Bilate irrigation scheme is located in the upper Bilate River basin, Sankura woreda. It was established in 2004 EC by the Federal Government of Ethiopia. The initially designed area was 305 ha. Its source of water is Bilate River diverted by constructed diversion weir having about 7.2-km length of the fully lined main canal. The command area is located on the left side of the river. Bilate irrigation scheme operates only once a year (December to May) with the other seasons being rain-fed, and/or the farmers have no interest to grow irrigated crops (Sankura Woreda Agricultural Office). All water users

Table 1 Soil textural class and bulk density for Bilate irrigation scheme

Field location	Soil depth (cm)	Particles size distribution (%)			Textural classes	Bulk density (g/cm^3)
		%Clay	%Silt	%Sand		
Head	0–30	28	28	44	Clay loam	1.30
	30–60	30	27	43	Clay loam	1.39
	60–100	42	24	34	Clay	1.31
Middle	0–30	30	30	40	Clay loam	1.28
	30–60	38	25	37	Clay loam	1.29
	60–100	50	22	28	Clay	1.23
Tail	0–30	32	30	38	Clay loam	1.35
	30–60	30	30	40	Clay loam	1.19
	60–100	35	30	35	Clay	1.19

Fig. 1 Current conditions for physical infrastructures in Bilate irrigation scheme

in the irrigation districts are smallholder farmers. The water users practice rotational irrigation based on their field location relative to the main canal. Farmers at the head and near the main canal receive irrigation water first as it is diverted downstream.

The dominant soil texture in the command area is clay loam for soil profiles up to the depth of about 60 cm and clay for soil profiles below this depth (soil laboratory results in Table 1). The major crops grown in the command area are maize, potato, onion, tomato, green pepper, and cabbage (Sankura Woreda Agricultural Office). Based on field observations, the division boxes and control gates currently malfunctioned except at headwork as indicated in Fig. 1 below. But the water division and flow controlling were done by local materials such as stones and soils. The cross sections of some unlined canals are very wide which may lead to water stagnation as indicated in Fig. 1 below.

The Furfuro irrigation scheme is located in the sub-basin of Dijjo watershed, in Wulberag woreda. It was established in 1999 EC by the regional government of SNNPRS. The initially designed area was 200 ha. Its source of water is Furfuro river diverted by

Table 2 Soil textural class and bulk density for Furfuro irrigation scheme

Field location	Soil depth (cm)	Particles size distribution (%)			Textural classes	Bulk density (g/cm^3)
		%Clay	%Silt	%Sand		
Head	0–30	35	38	27	Clay loam	1.28
	30–60	33	37	24	Clay loam	1.24
	60–100	37	37	26	Clay loam	1.26
Middle	0–30	35	40	23	Clay loam	1.30
	30–60	38	39	25	Clay loam	1.25
	60–100	50	18	32	Clay	1.21
Tail	0–30	38	28	34	Clay loam	1.22
	30–60	28	30	42	Clay loam	1.32
	60–100	56	16	28	Clay	1.21

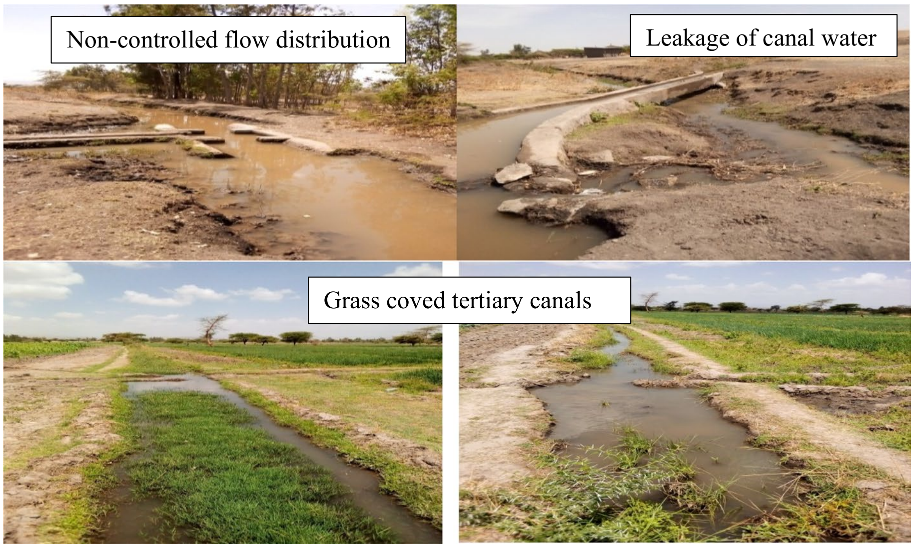


Fig. 2 Current conditions for physical infrastructures in Furfuro irrigation scheme

constructed diversion weir to the fully lined main canals found on the left and right sides of the river. The command areas are located on both sides of the river. Furfuro irrigation scheme also operates once a year (December to May) with the other seasons being rain-fed, and/or the farmers have no interest in irrigation (Wulberag Woreda Agricultural Office). All water users in the irrigation districts are small private growers. They receive irrigation water on a rotational basis depending on their field location relative to the main canal. Farmers at the head and near the main canal also receive water first.

The dominant soil texture in the command areas is clay loam at soil profiles up to the depth of about 60 cm and clay at soil profiles below this depth (soil laboratory result in Table 2). In its command area, major crops grown are maize, potato, onion, tomato, green pepper, cabbage, and carrot (Wulberag Worada Agricultural Office). Based on field observations, the division boxes and flow control gates are currently malfunctioned except at headwork as indicated in Fig. 2 below. The water division and control were done by local materials such as stones and soils. Most unlined tertiary canals have an unnecessarily cross-sectional size, and their waterway is covered by grass as indicated in Fig. 2. These may cause irrigation water stagnation and water exposed to evaporation losses.

Methods

Description of the study areas

The study was conducted at Sankura and Wulberag woredas, Silti Zone, southern Ethiopia, at a distance of about 208 km and 183 km to the southwest of Addis Ababa respectively. The study areas are located geographically in the range of 7°27′13″ to 7°40′10″N latitude, 38°5′17″ to 38°43′8″E longitude, and 1837- to 1897-m altitude. The area in Bilate and Furfuro irrigation schemes receives a mean annual rainfall of 953.3 mm and 1006.1 mm respectively (National Meteorological Service Agency). About 10.5–11.2% of rainfall is received from November to March which is considered the minor rainy season. The main rainfall season is from June up to September (Figs. 3 and 4).

As indicated in Figs. 5 and 6 below, the monthly rainfall is higher than the monthly reference evapotranspiration between the end of May and the beginning of October. This indicated that no need for irrigation application during this season. Since the monthly reference evapotranspiration is higher than monthly rainfall, the irrigation is critically significant during January; February, March, November, and December. However, in April, May, and October, supplementary irrigation may support rainfall shortage.

Field experimental layout

To collect and measure the relevant data at the field level, the three representative farmers' fields were selected as the head, middle, and tail-end water users in each irrigation scheme based on land tenure arrangements, water management practices, the willingness of the farmers, and main canal reach that utilize the irrigation water (Figs. 7 and 8).

Data collection

Primary data collection

Primary data were collected through formal and informal survey, frequent field observations and measurements, measurements of water flow in canals system and field level during irrigation, soil samples collection before and after irrigation, and measuring the moisture content of the soils in the selected irrigation fields. The soil samples were collected from each selected field at the head, middle, and tail end of each irrigation scheme. The soil samples were collected at three intervals of the soil horizon (0–30, 30–60, and 60–100 cm) since the soil profile variation is at 30-cm intervals in the study areas. Materials used were core samplers, augers, oven, measuring tapes, stopwatch, analytical balance, plastic bags, Parshall flumes, GPS, double ring infiltrometer, staff gauges, hammer, digital camera, floating objects, and others.

Secondary data collection

The climatic data like rainfall and maximum and minimum temperature for 37 years (1981–2018) were collected from National Meteorological Service Agency. However, average monthly data for relative humidity, wind speed, and sunshine hour were loaded

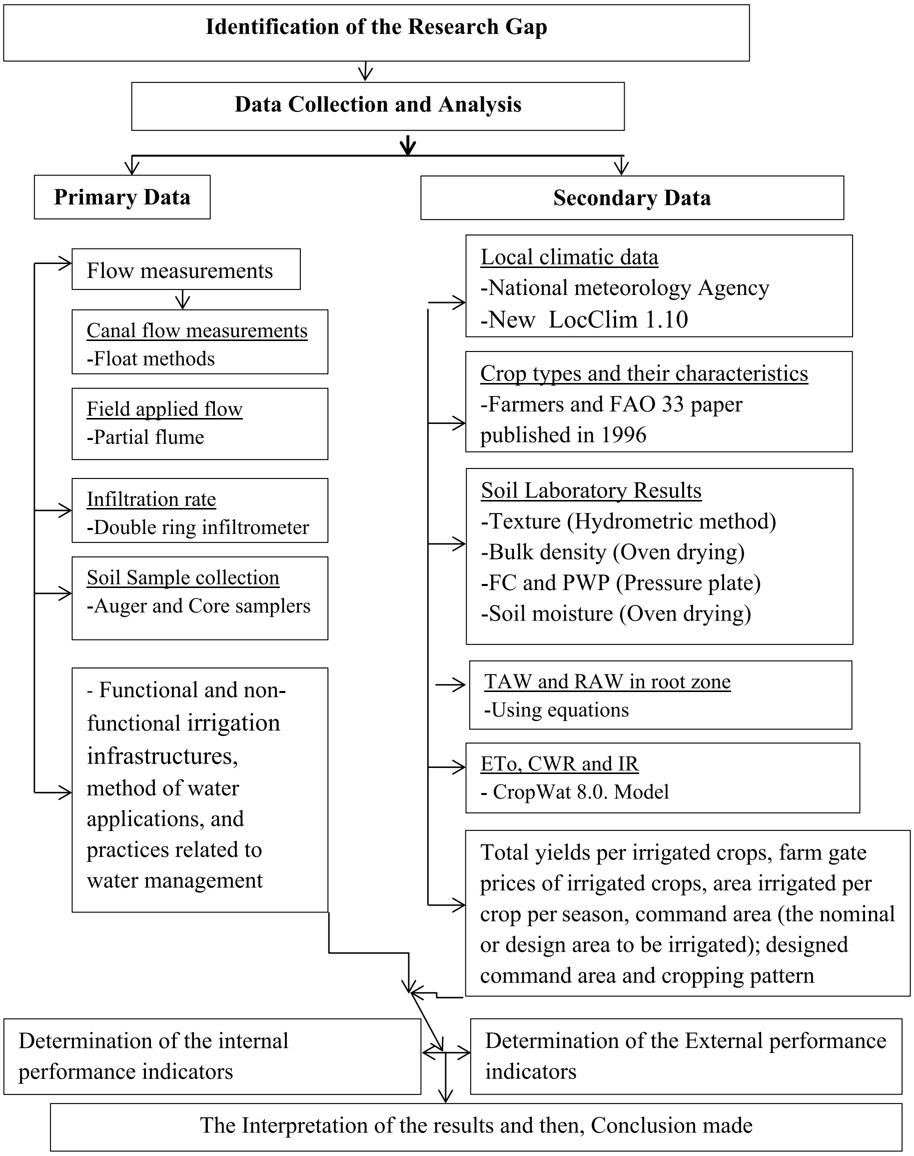


Fig. 3 Flow chart showing research methodology

using New_LocClim 1.10 software. The crop data (development stages, crop coefficient, rooting depth, critical depletion level, and yield response factor) were adopted from published papers [12–14]. Moreover, production and market price data (crop yield and local prices of the yield) and area size data (command area, initially irrigated area, and area irrigated during the study period) were collected from Silti Zone Water Resources Bureau, Sankura and Wulberag Woreda Agricultural and Revenue Offices.

Data analysis

Soil physical properties analysis

The soil's physical properties (bulk density, textural class, field capacity, permanent wilting point, and soil moisture content before and 2 days after irrigation) were analyzed in

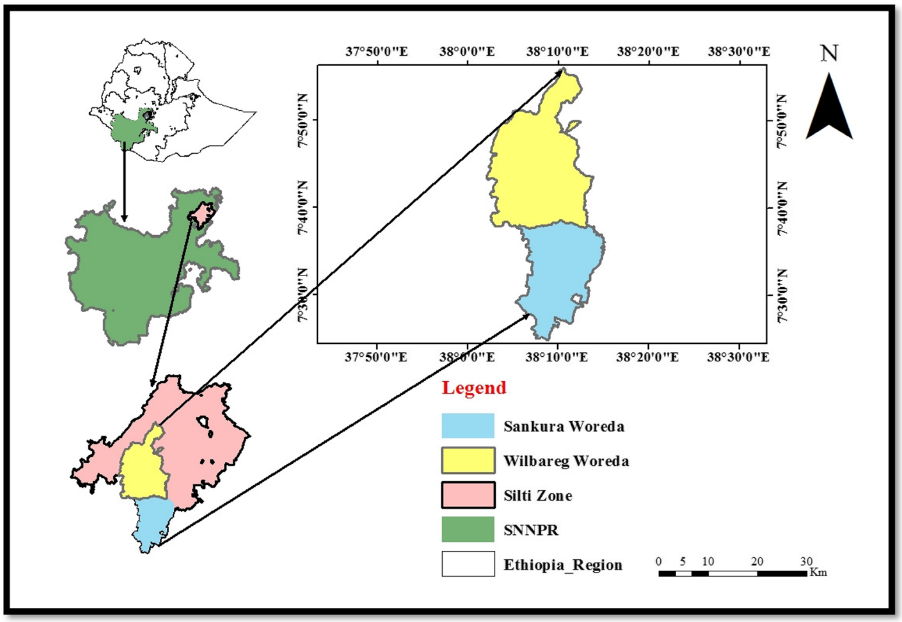


Fig. 4 Location map of the study areas

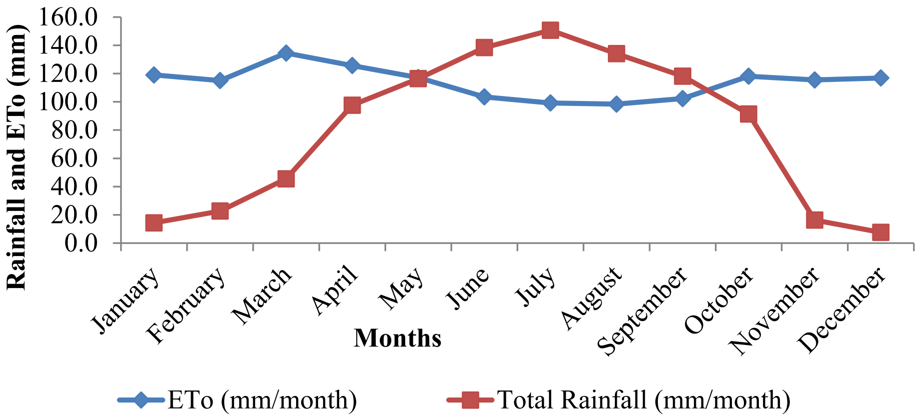


Fig. 5 Climatic water balance in Bilate irrigation scheme

the Areka Agricultural Research Center Laboratory and Ethiopia Construction Corporation and Research Soil Laboratory. But the infiltration rate was measured at the field level using a double ring infiltrometer having 30- and 60-cm diameters of the inner and outer ring respectively.

$$\mathrm{BD} = \frac{\text{Weight of dry soil(g)}}{\text{The volume of the same soil}(\mathrm{cm}^3)} \tag{3.1}$$

where BD is the soil bulk density (g/cm^3)

$$\mathrm{FC} = \frac{\text{Weight of water retained in a known volume of soil}}{\text{Weight of the same volume of dry soil}} \times 100 \tag{3.2}$$

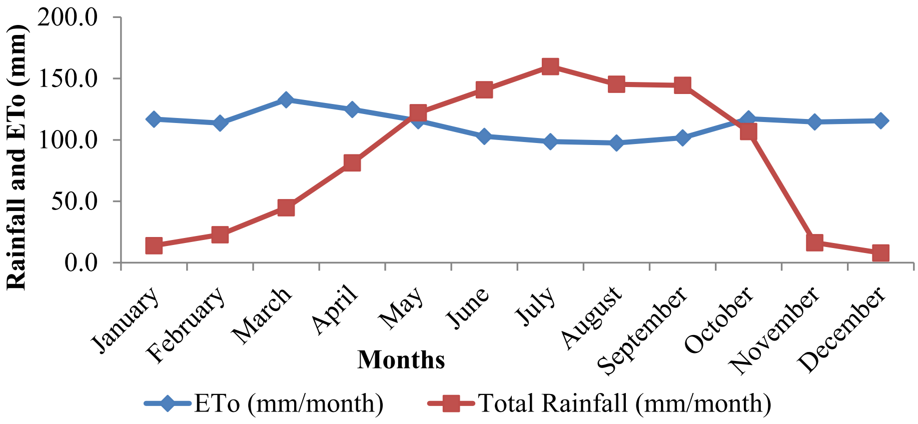


Fig. 6 Climatic water balance in Furfuro irrigation scheme

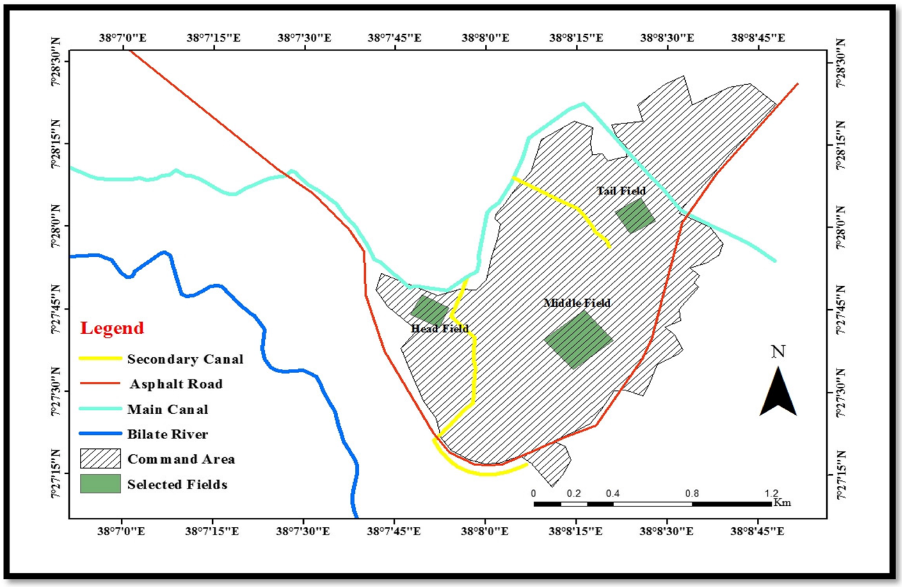


Fig. 7 Field layout of Bilate irrigation scheme

$$\mathrm{PWP} = \frac{\text{Weight of water retained in a known volume of soil}}{\text{Weight of the same volume of dry soil}} \times 100 \tag{3.3}$$

where FC is field capacity at 1/3 bars pressure and PWP is permanent wilting point at 15 bars.

The depth of irrigation water stored in the root zone was estimated by the depth of soil moisture content after irrigation minus the depth of soil moisture content before irrigation.

$$\%\mathrm{Wt} = \left(\frac{\text{Weight of wet soil(g)} - \text{weight of dry soil(g)}}{\text{Weight of dry soil(g)}}\right) \times 100 \tag{3.4}$$

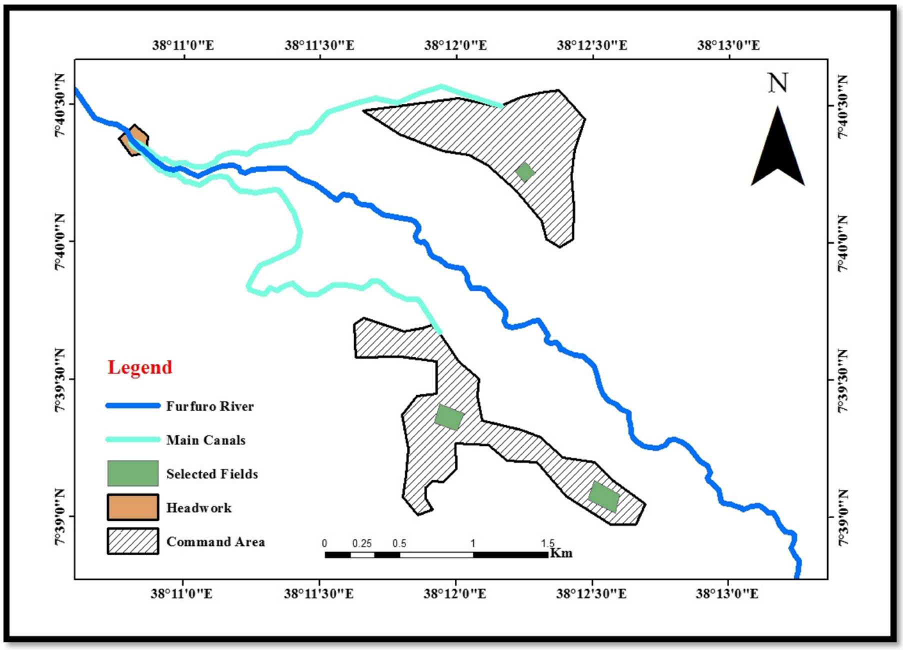


Fig. 8 Field layout of Furfuro irrigation scheme

$$\theta \mathrm{v} = \%\mathrm{Wt} \times \mathrm{BD} \tag{3.5}$$

$$\mathrm{D_m} = \theta \mathrm{v}(\text{fraction bases}) \times \mathrm{D_z} \tag{3.6}$$

where %Wt is gravimetric soil moisture content (%weight bases),θv is the volumetric soil moisture content (%), $\mathrm{D_m}$ is the depth of soil moisture contents at the effective root zone (mm), and $\mathrm{D_z}$ is the depth of the effective root zone (mm)

Depth of irrigation water applied

The irrigation water applied into each selected field was measured by 7.7-cm (3-inch) throat width Parshall flume. The gross depth of irrigation water applied was determined from the recorded application time, Parshall flume flow rate, and area of the irrigated field by Eq. (3.8) below.

$$\mathrm{T} = \frac{\mathrm{A} \times \mathrm{d}}{6\mathrm{q}} \tag{3.7}$$

$$\mathrm{d} = \frac{(6 \times \mathrm{T} \times \mathrm{q})}{\mathrm{A}} \tag{3.8}$$

where T is time (minute), d is gross irrigation water depth applied (cm), A is an area of the field ($\mathrm{m^2}$), and q is the flow rate of Parshall flume (l/s).

Depth of irrigation water needed before irrigation (RAW)

The readily available water at the effective root zone was computed from the total available water and depletion levels of each irrigated crop by Eq. (3.10). But the total available water at the effective root zone was computed by Eq. (3.9) [14].

$$\mathrm{TAW} = 1000(\mathrm{FC} - \mathrm{PWP}) \times \mathrm{BD} \times \mathrm{Dz} \tag{3.9}$$

$$\mathrm{RAW} = \mathrm{TAW} \times \mathrm{p} \tag{3.10}$$

where TAW is total available water (mm), FC is the gravimetric soil moisture content at field capacity (fraction), PWP is the gravimetric soil moisture content at permanent wilting point (fraction), Dz is the effective root zone of a crop (m), BD is bulk density (g/cm^3), RAW is readily available water (mm), and p is critical depletion level for each crop (fraction).

Canal flow discharge measurement

The flow discharges in each canal section were measured by area-velocity methods using a floating object [5, 19, 30].

$$\mathrm{Q} = \mathrm{V}_{\mathrm{mean}} \times \mathrm{A}_{\mathrm{w}} \tag{3.11}$$

where $\mathrm{V}_{\mathrm{mean}}$ is average flow velocity (m/s), A_{w} is canal wetted cross-section area (m^2), and Q is flowing discharges (m^3/s).

$$\mathrm{V}_{\mathrm{s}} = \frac{\mathrm{L}}{\mathrm{t}} \tag{3.12}$$

$$\mathrm{V}_{\mathrm{mean}} = \mathrm{k} \times \mathrm{V}_{\mathrm{s}} \tag{3.13}$$

where L is the length of canal that the floating object traveled (m), t is the time taken by the floating object from started point to the marked point (seconds), V_{s} is the surface velocity of the flow (m/s), and k is correction coefficient.

Crop and irrigation water requirement

The crop and irrigation water requirements were determined in CROPWAT 8.0 model [11]. Then, the total crop water requirement was computed from the crop water requirement of each cultivated crop by Eq. (3.14), while the total net irrigation water requirement was computed from the irrigation requirements of each cultivated crop by Eq. (3.15).

Then, the volume of seasonal crop water demand in the whole irrigated area of each irrigation scheme was computed using the Eq. (3.16). But the volume of seasonal irrigation water demand in the whole irrigated area was computed by Eq. (3.17).

$$\mathrm{CWR}_{total} = \sum_{\mathrm{i}=1}^{6} \frac{\mathrm{CWR}_{i} \times \text{area of crop(i)}}{\text{Total area}} \tag{3.14}$$

$$\mathrm{IR}_{total} = \sum_{\mathrm{i}=1}^{7} \frac{\mathrm{IR}_{i} \times \text{area of crop(i)}}{\text{Total area}} \tag{3.15}$$

$$\mathrm{CWR_v} = 10 \times \mathrm{CWR_{total}} \times \mathrm{A_{total}} \tag{3.16}$$

$$\mathrm{IR_v} = 10 \times \mathrm{IR_{total}} \times \mathrm{A_{total}} \tag{3.17}$$

where $\mathrm{CWR}_{(i)}$ and $\mathrm{IR}_{(i)}$ are the depth of crop and irrigation requirements for each crop (mm) respectively, $\mathrm{CWR_{total}}$ is the depth of seasonal crop water demand for whole scheme irrigated area (mm), $\mathrm{IR_{total}}$ is the depth of seasonal irrigation water demand for whole scheme irrigated area (mm), $\mathrm{CWR_v}$ is the volume of seasonal crop water demand ($\mathrm{m^3}$), $\mathrm{IR_v}$ is the volume of seasonal irrigation water demand ($\mathrm{m^3}$), and $\mathrm{A_{total}}$ is total irrigated area (ha).

Peak irrigation flow demand of the irrigation schemes

The peak scheme irrigation water demand for the whole scheme's irrigated area was computed using Eq. (3.18). The reason for using project irrigation efficiency is that the scheme irrigation requirement includes net irrigation water requirement as well as irrigation water losses at conveyance and field canals system and field level.

$$\mathrm{GIR_{max}} = \frac{\mathrm{IRn_{max}}}{\mathrm{E_P}} \tag{3.18}$$

$$q\left(\frac{l/s}{ha}\right) = \frac{(0.001 \times GIR_{max} \times 10,000 \times 1000)}{B_{max} \times 24 \times 60 \times 60} \tag{3.19}$$

$$\mathrm{q\ (l/s) = q\ (l/s/ha) \times A_{total}} \tag{3.20}$$

where $\mathrm{B_{max}}$ is the maximum total growing period, $\mathrm{GIR_{max}}$ is the maximum gross irrigation requirement, $\mathrm{IRn_{max}}$ is the maximum net irrigation requirement, and $\mathrm{E_p}$ is project efficiency.

Estimation of internal performance indicators

Conveyance efficiency

The conveyance efficiency was computed as the ratio of outflow-to-inflow discharges by Eq. (3. 21) [29].

$$E_c = \frac{\text{Outflow rate from the canal sections}}{\text{Inflow rate into the same canal sections}} \times 100 \tag{3.21}$$

where Ec is conveyance efficiency.

Field application efficiency

Field application efficiency was estimated as the ratio of the depth of irrigation water stored at the effective root zone to the depth of irrigation water applied to the field using Eq. (3.22) [29].

$$E_a = \frac{\text{Depth of irrigation water stored in the root zone}}{\text{Depth of irrigation water supplied to the field}} \times 100 \tag{3.22}$$

where E_a is field application efficiency.

Water storage efficiency

The water storage efficiency was estimated as the ratio of the depth of irrigation water stored during irrigation to the depth of water needed before irrigation at the effective root zone by Eq. (3.23) [16].

$$E_s = \frac{\text{Depth of irrigation water stored during irrigation}}{\text{Depth of irrigation water needed before irrigation}} \times 100 \tag{3.23}$$

where the depth of irrigation water needed before irrigation is the readily available water (RAW) of the soil in the effective root zone and E_s is storage efficiency (%).

To determine the depth of irrigation water stored at the effective root zone, soil samples were collected from cropped root zone before and 2 days after irrigation from each selected field at head, middle, and tail end of each irrigation scheme. Then, soil moisture content in millimeter was determined for these collected soil samples before and after irrigation following methods mentioned above section. Finally, depth of irrigation water stored at the effective root zone was determined by after irrigation soil moisture content minus before irrigation soil moisture content.

Overall irrigation efficiency

The overall irrigation efficiency was computed by Eq. (3.24) [28]:

$$\mathrm{E_o} = (\mathrm{E_c} \times \mathrm{E_a}) \times 100 \tag{3.24}$$

where E_o is the overall irrigation efficiency (%), E_c is conveyance efficiency (fraction), and E_a is the field application efficiency (fraction).

Irrigation uniformity

Christian's uniformity coefficient was computed for three selected furrow at head, middle, and tail-end selected fields for each irrigation scheme. Then, for each selected field, the Christian's uniformity coefficient was the average values of the Christian's uniformity coefficient of the three selected furrow of that selected field. The Christian's uniformity coefficient was computed following suggestion made by [29]:

$$CU = \left(1 - \frac{d}{D}\right) \times 100 \tag{3.25}$$

where CU is Christian's uniformity coefficient (%), D is average depth of water stored (mm), and d is average of absolute deviation depth of stored water from the mean (mm).

Estimation of external performance indicators

The selected external performance indicators were evaluated in this study: water delivery performance indicators (relative water supply and relative irrigation supply), irrigated agriculture performance indicators (output per unit irrigated area, output per unit command area, output per unit irrigation supply, and output per unit water consumed), and physical performance indicators (sustainability of irrigated area and irrigation ratio).

Water delivery performance indicators

Relative water supply

The relative water supply was computed as the ratio of total net water applied (irrigation water plus effective rainfall) to the total net crop water demand in volume [27].

$$\text{Relative water supply}\,(\text{RWS}) = \frac{\text{Total net water applied}\,(\text{m}^3)}{\text{Total net crop water demand}\,(\text{m}^3)} \tag{3.26}$$

Relative irrigation supply

The relative irrigation supply was determined as the ratio of total net irrigation water applied to the total net irrigation water demand in volume (i.e., crop evapotranspiration minus effective rainfall) [26].

$$\text{Relative irrigation supply}\,(\text{RIS}) = \frac{\text{Total net Irrigation applied}\,(\text{m}^3)}{\text{Total net irrigation water demand}\,(\text{m}^3)} \tag{3.27}$$

Irrigated agriculture output performance indicators

Four basic irrigated agriculture performance indicators (output per unit irrigated area, output per unit command area, output per unit irrigation supply, and output per unit water consumed) were computed as below [25].

$$\text{Output per unit irrigated area}\left(\frac{\text{US\$}}{\text{ha}}\right) = \frac{\text{Production}}{\text{Currently irrigated area}} \tag{3.28}$$

$$\text{Output per unit command area}\left(\frac{\text{US\$}}{\text{ha}}\right) = \frac{\text{Production}}{\text{Command area}} \tag{3.29}$$

$$\text{Output per unit irrigation supply}\left(\frac{\text{US\$}}{\text{m}^3}\right) = \frac{\text{Production}}{\text{Diverted irrigation supply}} \tag{3.30}$$

$$\text{Output per unit water consumed}\left(\frac{\text{US\$}}{\text{m}^3}\right) = \frac{\text{Production}}{\text{The volume of water consumed by ET}} \tag{3.31}$$

where production is the output of the irrigated area measured at the local market, irrigated area is the sum of the areas irrigated during the period of analysis, command area is the designed area, diverted irrigation supply is the volume of irrigation water diverted throughout the crop growing period, and volume of water consumed by ET is the actual evapotranspiration of the whole cultivated crops.

Physical performance indicators

The designed command area, initially irrigated area, and currently irrigated area in Bilate irrigation scheme were 305, 325.5, and 332.25 hectare respectively, whereas the command/designed area, initially irrigated area, and currently irrigated area in Furfuro irrigation scheme were 200, 209.5, and 221 ha respectively. This indicated that the interest of farmers to use irrigation was high in both irrigation schemes. However, the competition of water causes the conflict among water users; hence, it may need increasing of irrigation water amount from the sources in both irrigation schemes.

Two physical performance indicators (i.e., irrigation ratio and sustainability of irrigated area) were analyzed as below [4, 25].

$$\text{Sustainability of irrigated area} = \frac{\text{Currently irrigated area}}{\text{Initially irrigated area}} \tag{3.32}$$

$$\text{Irrigation ratio} = \frac{\text{Currently irrigated area}}{\text{Command area}} \tag{3.33}$$

Comparison between two irrigation schemes

In this study, the comparison between Bilate and Furfuro irrigation schemes was made based on estimated values of the external performance indicators (such as relative water supply, relative irrigation supply, water delivery capacity, output per unit irrigated area, output per unit command area, output per unit irrigation supply, output per unit water consumed, sustainability of irrigated area, and irrigation ratio).

Results and discussion

Soil physical properties analysis

The analyzed soil laboratory result indicated that the dominant soil texture is clay loam in the upper two soil profiles up to 60-cm soil depth in all selected fields of two irrigation schemes. But below 60-cm soil depth, the dominant soil texture is clay in each selected field of two irrigation schemes, except in the header field of Furfuro irrigation scheme which had clay loam texture in whole tested soil depths as indicated in Tables 1 and 2.

The result obtained shows that the bulk density values of clay loam textured soils are found in the range of 1.19 to 1.39 g/cm^3, and clay textured soils are found in the range of 1.19 to 1.31 g/cm^3 in each selected field of two irrigation schemes as indicated in the Tables 1 and 2. The ideal bulk density value for better plant root growth is less than 1.10 g/cm^3 for clay loam and clay textured soils [32].

However, the same source proposed the bulk densities that affect root growth are (1.10–1.49 g/cm^3) and (1.10–1.39 g/cm^3) for clay loam and clay soils respectively. The results obtained in this study show that the bulk densities may affect the root growth according to USDA/NRCS [32]. This implied that the soil might be highly compacted, and this compaction of soil reduces pore space and high resistance to root penetration.

The results obtained for field capacity, permanent wilting point, and total available water at effective root depth show that the total available water was between 167.7 and 192.7 mm/m) in each selected field of the two irrigation schemes. The average values of total available water obtained from selected fields of each irrigation scheme were used as input data for CROPWAT 8.0 model. The average values for each irrigation scheme were obtained as the average of the total available water measured from the selected fields at the head, middle, and tail end of each irrigation scheme. The average total available

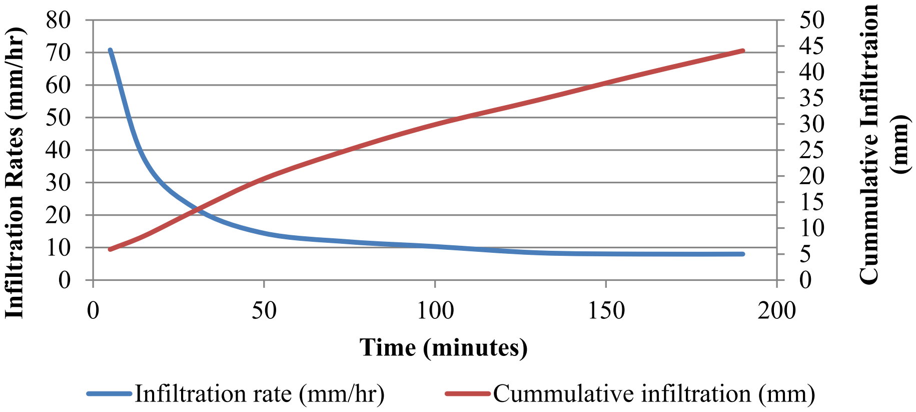


Fig. 9 Cumulative and basic infiltration rate for Bilate irrigation scheme

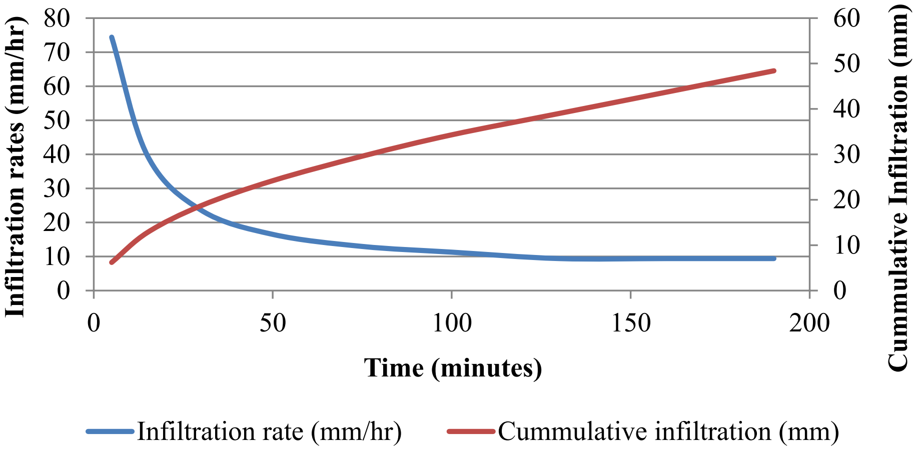


Fig. 10 Cumulative and basic infiltration rate for Furfuro irrigation scheme

water obtained in this study was 179.5 and 180.1 mm/m for Bilate and Furfuro irrigation schemes respectively.

The field-measured values for basic infiltration rates were 8 and 9 mm/h in Bilate and Furfuro irrigation schemes, respectively, as indicated Figs. 9 and 10. Since the dominant soil texture was clay loam, especially upper two soil profile depths (i.e., up to 60-cm soil depth) in two irrigation schemes, the obtained values for basic infiltration rates were in agreement with recommended value for the same soil types [13]. The obtained values for basic infiltration rates were used for evaluation of farmer application rate of the irrigation water and also used as input data for CROPWAT 8.0 model to determine the irrigation scheduling.

Field application efficiency

The result obtained for field application efficiencies at the head, middle, and tail-end fields was 61.1%, 52.8%, and 53.7% respectively with an average application efficiency of 55.9% in Bilate irrigation scheme, while the results obtained for application efficiencies at the head, middle, and tail-end fields were 51.9%, 64.9%, and 57.3% respectively

Table 3 Field application efficiency for Bilate and Furfuro irrigation schemes

Field location	Bilate irrigation scheme			Furfuro irrigation scheme		
	WAD (mm)	SMS (mm)	Ea (%)	WAD (mm)	SMS (mm)	Ea (%)
Head	61.2	37.4	61.1	32.2	16.7	51.9
Middle	65.5	34.6	52.8	40.4	26.2	64.9
Tail end	38.6	20.7	53.7	28.9	16.5	57.3
Average			55.9			58.0

WAD is the depth of applied irrigation water, and *SMS* is soil moisture stored

Table 4 Water storage efficiency for Bilate and Furfuro irrigation schemes

Field location	Bilate irrigation scheme			Furfuro irrigation scheme		
	SMS (mm)	RAW (mm)	Es (%)	SMS (mm)	RAW (mm)	Es (%)
Head	37.4	94.8	39.4	16.72	28.9	57.9
Middle	34.6	83.6	41.4	26.21	66.6	39.3
Tail end	20.7	26.5	78.1	16.54	39.1	42.3
Average			53.0			46.5

SMS is soil moisture stored, and RAW is readily available water

with the average application efficiency of 58% in Furfuro irrigation scheme as indicated in Table 3. This indicated that the field application efficiency varies from field to field in the similar farming system, methods of irrigation water application, and field operation strategies, but the difference may be the on-field water management.

The recommended maximum attainable application efficiency for surface irrigation systems is 55–70% [11]. The average field application efficiencies obtained in this study were within the recommended standard mentioned above for two irrigation schemes. The main reason might be the applied water is less than the soil moisture deficit, farmers used closed-end furrow (which may minimize runoff losses), the type of soil texture is clayey, and the compactness of the soil in the study area (which may reduce deep percolation losses). The obtained application efficiencies of this study imply the need to take the improvement measures of on-field water management and day-to-day operations.

Water storage efficiency

A result indicated that the water storage efficiencies at the head, middle, and tail field were 39.4%, 41.4%, and 78.1% with average of 53.0% for Bilate irrigation scheme and 57.9%, 39.4%, and 42.3% with average of 46.5% for Furfuro irrigation schemes respectively as indicated in Table 4.

The recommended water storage efficiency for furrow irrigation systems is 63% [21, 27]. Thus, the water storage efficiencies obtained in this study were very poor in the two irrigation schemes. This indicated that may the applied irrigation water was not satisfied the soil moisture deficit in the two irrigation schemes. This reflects directly soil moisture stress and inadequacy of irrigation water applied. The main reasons might be the applied irrigation water was below an intended water demand, farmers practicing fast application rates of irrigation water than soil infiltration rate, and/or farmers lacking awareness of different crop needs a different amount of water.

Table 5 Christian's coefficient uniformity for Bilate irrigation schemes

		Moisture stored			**Mean**	**CU (%)**
Head selected field						
Beginning furrow	Total moisture stored	39.0	38.8	41.0	39.6	94.3
	Absolute deviation from mean	1.6	1.5	3.6	2.2	
Middle furrow	Total moisture stored	43.6	32.5	36.0	37.4	88.9
	Absolute deviation from mean	6.2	4.9	1.4	4.1	
Bottom furrow	Total moisture stored	35.3	34.3	35.8	35.1	93.6
	Absolute deviation from mean	2.1	3.1	1.5	2.2	
Average for field						**92.3**
Middle selected field						
Beginning furrow	Total moisture stored	41.0	36.1	34.7	37.3	92.8
	Absolute deviation from mean	6.4	1.5	0.2	2.7	
Middle furrow	Total moisture stored	37.9	34.1	33.6	35.2	95.4
	Absolute deviation from mean	3.3	0.5	1.0	1.6	
Bottom furrow	Total moisture stored	32.8	30.5	30.7	31.3	89.6
	Absolute deviation from mean	1.8	4.1	3.9	3.3	
Average for field						**92.6**
Tail selected field						
Beginning furrow	Total moisture stored	16.1	18.3	24.3	19.6	81.8
	Absolute deviation from mean	4.6	2.4	3.6	3.6	
Middle furrow	Total moisture stored	18.3	22.0	22.7	21.0	91.0
	Absolute deviation from mean	2.5	1.2	2.0	1.9	
Bottom furrow	Total moisture stored	19.4	22.3	23.1	21.6	91.9
	Absolute deviation from mean	1.3	1.6	2.4	1.8	
Average for field						**88.2**

Table 6 Depth of moisture stored in each test points in Bilate irrigation scheme

Field location	**Furrow one**			**Furrow two**			**Furrow three**		
Head	39.0	38.8	41.0	43.6	32.5	36.0	35.3	34.3	35.8
Middle	41.0	36.1	34.7	37.9	34.1	33.6	32.8	30.5	30.7
Tail	16.1	18.3	24.3	18.3	22.0	22.7	19.4	22.3	23.1

Irrigation uniformity

The average Christian's uniformity coefficients were (92.3, 92.6, and 88.2%) and (91.0, 93.6, and 94.3%) for selected fields at head, middle, and tail end in Bilate and Furfuro irrigation schemes respectively as indicated in Table 5. The irrigation uniformity values obtained in present study for all selected furrows as well as all selected fields in each irrigation schemes were much higher than the advanced furrow irrigation systems, which is 70% [27]. Therefore, the irrigation uniformities of the two irrigation schemes were very good; the reason for this might be the farmers used short length at most 20-m furrow length, closed-end furrow practices, and good land grading practices in the study area (Tables 6, 7 and 8).

Table 7 Depth of moisture stored in each test points in Furfuro irrigation scheme

Field location	Furrow one			Furrow two			Furrow three		
Head	14.7	16.9	19.0	14.6	16.5	19.1	14.3	16.7	18.6
Middle	22.4	26.9	26.3	25.0	27.2	26.7	23.8	31.1	26.5
Tail	17.0	17.8	17.0	16.1	16.8	14.3	17.1	15.0	17.9

Table 8 Christian's coefficient uniformity for Furfuro irrigation schemes

		Moisture stored			Mean	CU (%)
Head selected field						
Beginning furrow	Total moisture stored	14.7	16.9	19.0	16.9	91.1
	Absolute deviation from mean	2.0	0.2	2.3	1.5	
Middle furrow	Total moisture stored	14.6	16.5	19.1	16.7	90.6
	Absolute deviation from mean	2.2	0.2	2.4	1.6	
Bottom furrow	Total moisture stored	14.3	16.7	18.6	16.5	91.3
	Absolute deviation from mean	2.4	0.0	1.9	1.4	
Average for field						**91.0**
Middle selected field						
Beginning furrow	Total moisture stored	22.4	26.9	26.3	25.2	93.8
	Absolute deviation from mean	3.8	0.7	0.1	1.6	
Middle furrow	Total moisture stored	25.0	27.2	26.7	26.3	96.5
	Absolute deviation from mean	1.3	1.0	0.5	0.9	
Bottom furrow	Total moisture stored	23.8	31.1	26.5	27.1	90.6
	Absolute deviation from mean	2.5	4.9	0.3	2.6	
Average for field						**93.6**
Tail selected field						
Beginning furrow	Total moisture stored	17.0	17.8	17.0	17.2	96.0
	Absolute deviation from mean	0.4	1.2	0.4	0.7	
Middle furrow	Total moisture stored	16.1	16.8	14.3	15.7	93.9
	Absolute deviation from mean	0.4	0.2	2.2	1.0	
Bottom furrow	Total moisture stored	17.1	15.0	17.9	16.7	93.2
	Absolute deviation from mean	0.5	1.5	1.4	1.1	
Average for field						**94.3**

Conveyance efficiency

The conveyance efficiency and loss were estimated from the inflow and outflow discharges measured in main, secondary, and tertiary canal sections as indicated in Tables 9 and 10 for two irrigation schemes. The recommended conveyance efficiency for lined canals of any length is 95%. For earthen canals with clay soil could be 80%, 85%, and 90% for canal lengths of > 2000 m, 200–2000 m, and < 200 m, respectively [15].

Thus, except at 900-m lined main canal section of Bilate irrigation scheme and 5300-m lined main canal section of Furfuro irrigation scheme, the results of conveyance efficiencies at lined canals were below recommended value. Moreover, estimated values of conveyance efficiencies for unlined tertiary canals sections were below the recommended values in two irrigation schemes. The main reason might be evaporation losses, malfunctioning of control gates, high sedimentation, illegal

Table 9 Canal conveyance efficiency and loss for Bilate irrigation scheme

Canal types	L_c (m)	Q (l/s)	Conveyance efficiencies (%)	Conveyance loses (l/s)/100 m
Main canal	7200	282.60 257.09	91	0.4
	900	168.18 160.79	96	0.8
	1500	82.64 77.24	93	0.4
Secondary canal	400	78.86 68.48	87	2.6
	210	20.66 18.32	89	1.1
	106	5.22 4.60	88	0.6
Tertiary-1	115	26.58 15.20	57	9.90
Tertiary-2	96	20.18 13.51	67	6.94
Tertiary-3	120	8.63 4.92	57	3.09
Tertiary-4	105	10.83 6.59	61	4.03

Table 10 Canal conveyance efficiency and loss for Furfuro irrigation scheme

Canal types	Lc (m)	Q (l/s)	Conveyance efficiencies (%)	Conveyance loses (l/s)/m
Main canal-1	5300	88.443 84.766	96	0.069
Main canal-2	6100	43.184 39.200	91	0.065
Tertiary-1	380	18.087 10.267	57	2.06
Tertiary-2	210	15.108 9.562	63	2.64

L_c is canal length, and Q is flow discharge

water turnouts in main and secondary canals, water stagnation, grass covers of the canals' waterway, and canal size widening.

Thus, more water was lost in unlined canal sections, because of seepage and/or leakage losses, and their cross section was widened, and stagnation of water was common, which exposed to evaporation losses. Hence, the results of conveyance efficiencies and losses indicated high losses of irrigation water in conveyance systems of two irrigation schemes that may influence the irrigation adequacy.

Table 11 Overall irrigation efficiency for Bilate and Furfuro irrigation schemes

Efficiencies %	Bilate irrigation scheme	Furfuro irrigation scheme
Overall conveyance efficiency	78.6	76.7
Average application efficiency	55.9	58
Overall irrigation efficiency	28	32

Table 12 Relative water supply and relative irrigation supply for two schemes

Scheme	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
Bilate	945,968	701,115	1,392,385	1,147,532	0.68	0.61
Furfuro	801,699	685,073	1,009,465	892,839	0.79	0.77

Overall irrigation efficiency

According to Table 11, the overall irrigation efficiencies obtained in this study were 28 and 32% for Bilate and Furfuro irrigation schemes respectively. Rai et al. [29] suggested that the overall irrigation efficiency values between 50 and 60% are good, 40% are reasonable, while 20–30% are poor. Thus, the overall irrigation efficiencies recorded in this study were poor; the reason might be losses of water in conveyance systems.

External performance indicators

Water delivery performance indicators

The results obtained on water delivery indicators (relative water supply and relative irrigation supply) were discussed in Table 12.

The result in Table 12 indicated that the relative irrigation supplies were 0.61 and 0.77 for Bilate and Furfuro irrigation schemes respectively. Molden et al. [25] suggested that the relative irrigation supply value of one is better than the higher or lower values for any irrigation scheme. The results obtained in this study show that the relative irrigation supplies were below one for the two irrigation schemes. This indicated that applied water is not tightly matched to irrigation water demand in the two irrigation schemes. The reason might be the losses of irrigation water in the conveyance system, lack of awareness of crop water demand, and expansion of the irrigated area. The results obtained for relative water supplies were 0.68 and 0.79 for Bilate and Furfuro irrigation schemes. These results implied that the sum of irrigation water applied and effective rainfall did not satisfy the crop water demands in the two irrigation schemes.

Irrigated agricultural output performance indicators

The results obtained in this study for irrigated agriculture performance indicators those evaluated as land productivity (output per unit irrigated area and output per unit command area) and water productivity (output per unit irrigation supply and output per unit water consumed) were indicated in Table 13 below.

Table 13 Land and water productivity for Bilate and Furfuro irrigation schemes

Irrigation schemes	Bilate	Furfuro
Irrigated area during this study (ha)	332.25	221
Production from total irrigated area (US$)	1,375,651.8	393,701.6
Designed area (ha)	305	200
Total irrigation water applied (m^3/season)	1,460,656	1,427,236
CWR (m^3/season)	1,392,385	1,009,465
Output per unit irrigated area (US$/ha)	4140.4	1781.5
Output per unit command area (US$/ha)	4510.3	1968.5
Output per unit irrigation supply (US$/$m^3$)	0.94	0.28
Output per unit water consumed (US$/$m^3$)	0.99	0.39

Output per unit irrigated area

According to Table 13, the results obtained on output per unit irrigated area were 4140.4 and 1781.5 US$/ha in Bilate and Furfuro irrigation schemes respectively. The variation between the results of output per unit irrigated area among two irrigation schemes was 2358.9 US$/ha. The study conducted by Degirmenci et al. [8] in 12 irrigation schemes in the Southeastern Anatolia project suggested that the variation between output per irrigated area among various irrigation schemes was in the range of (308–5771 US$/ha). Thus, the result obtained in the present study indicated that the variation of output per irrigated area in two irrigation schemes was in the recommended range of Degimenci et al. [8].

Output per unit command area

According to Table 13, the results of output per unit command area were 4510.3 US$/ha and 1968.5 US$/ha for Bilate and Furfuro irrigation schemes respectively. The variation between the results of output per unit command area among two irrigation schemes was 2541.8 US$/ha. Degirmenci et al. [8] suggested that the variation between the output per unit command area could be in the range of (1223–9436 US$/ha) among various irrigation schemes. Thus, the results obtained in this study showed that the variation between the output per unit command area among Bilate and Furfuro irrigation schemes was in the recommended range of Degimenci et al. [8].

The result of this study indicated that the output per unit command area is better than output per unit irrigated area in two irrigation schemes. This is evidence that there is an effect thereby expansion of the irrigated area by 27.25 ha in Bilate and 21 ha in Furfuro irrigation schemes relative to the designed command area without delivering additional irrigation water.

Output per unit irrigation supply

The result obtained in this study on output per unit irrigation supply was 0.94 US$/$m^3$ and 0.28 US$/$m^3$ for Bilate and Furfuro irrigation schemes respectively. Cakmak and Beyr [5] conducted a study on 60 irrigation schemes found in Kizilirmak Basin, Turkey, and suggested the values for output per unit of irrigation supply could be in the range of (0.03–2.21 US$/$m^3$). Thus, the result of output per irrigation supply was in the recommended range of Cakmak and Beyr [5] for two irrigation scheme.

Output per unit of water consumed

The results obtained in this study on output per unit of water consumed were 0.99 US$/m^3 and 0.39 US$/m^3 in Bilate and Furfuro irrigation schemes respectively. Molden et al. [25] suggested that the output per unit of water consumed for irrigation schemes could be in the range of (0.03–0.91 US$/m^3). Accordingly, the result of output per water consumed for Furfuro irrigation scheme was in the recommended range of Molden et al. [25], while the result of output per water consumed for Bilate irrigation scheme was beyond recommended range, obtained by Molden et al. [25]. The reason might be farmers use a high level of agricultural inputs, and the command area may have better soil fertility.

The output per unit irrigated area and output per unit command area are termed land productivity, while output per unit irrigation supply and output per unit water consumed are termed water productivity. Therefore, Bilate irrigation scheme had better land and water productivity than Furfuro irrigation scheme.

Physical performance indicators

Sustainability of irrigated area

According to Table 14, the result of sustainability of irrigated area for Bilate and Furfuro irrigation schemes was 1.02 and 1.05, respectively. This indicates that actual irrigated areas during the study season were 102% and 105% of the initially irrigated area in Bilate and Furfuro irrigation schemes respectively. Therefore, irrigated areas of the schemes were expanded compared with the initially irrigated area. Various studies reported similar values, for example, Agide [1], Kassa and Ayana [20], and Tadesse [31] reported the values of 1.22 for Golgota irrigation scheme, 1.08 for Tahtay Tsalit irrigation scheme, and 1.2 for Bobe irrigation scheme respectively, who conducted their studies in Ethiopia.

Irrigation ratio

According to Table 14, the results of irrigation ratio in Bilate and Furfuro irrigation schemes were 1.09 and 1.11, respectively. This means that actual irrigated areas during the study season were 109 and 111% of the designed command in Bilate and Furfuro irrigation schemes. This means that the irrigated lands were expanded in these irrigation scheme areas. The reasons might be the self-initiation and interest of farmers within the schemes command areas to irrigate their land due to good land productivity as better soil fertilities of the areas and interest coming from neighboring farmers to irrigate extra land in addition to the designed area. This result agrees with Minichil [23] report for Kulech schemes.

Table 14 Irrigation ratio and sustainability of irrigated area for two schemes

Schemes	Currently irrigated area (ha)	Actual irrigated land in any season (ha)	Designed area (ha)	Sustainability of irrigated area	Irrigation ratio
Bilate	332.25	325.5	305	1.02	1.09
Furfuro	221	209.5	200	1.05	1.11

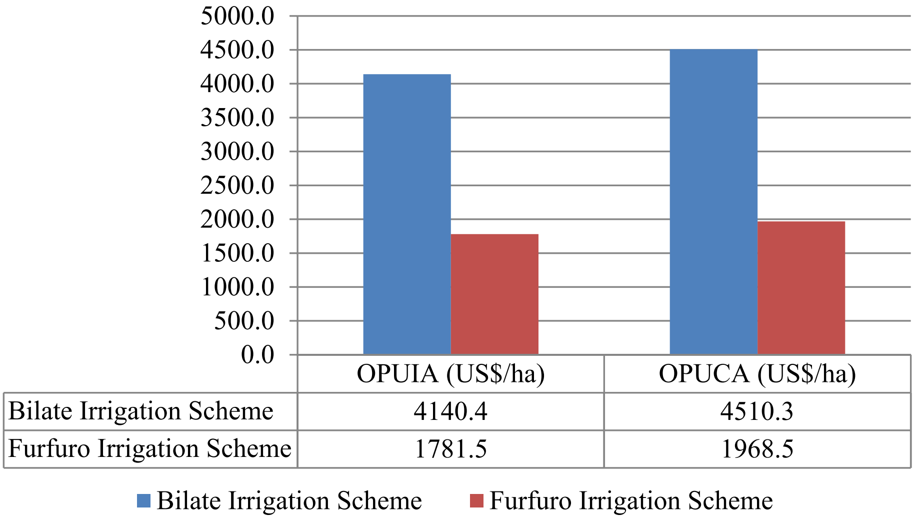
Comparison made between Bilate and Furfuro irrigation schemes

As indicated in Tables 9 and 10, more irrigation water was lost in the conveyance systems of Bilate irrigation scheme than Furfuro irrigation scheme. The reason might be higher canal sedimentation, illegal water turnouts, and malfunctioned division boxes and flow control canals in Bilate irrigation scheme than Furfuro irrigation scheme.

As indicated in Table 12 above, the relative water supply and relative irrigation supply values obtained were low in two irrigation schemes, depicting that, disregarding the distribution of the supply, the scarcity of irrigation water was being supplied much less than the demand. The result obtained for relative water supply and relative irrigation supply were below acceptable values for two irrigation schemes. But Furfuro irrigation scheme had relatively better values of relative water supply and relative irrigation supply than Bilate scheme. In Furfuro irrigation scheme, there is no competition to irrigation water; hence, farmers applied the irrigation water as much as amount of their interest. However, in Bilate irrigation scheme, there was high competition of water.

As indicated in Table 14 above, the result obtained in this study for the sustainability of the irrigated area and irrigation ratio was within an acceptable range of [7, 25] recommendation. This indicated that the irrigated areas were equally expanding for the two irrigation schemes. Thus, in terms of physical performance indicators, there was no difference between these two schemes' performance; hence, the irrigated land is currently expanded. This implied that the shortage of delivered irrigation water never reduces the farmers' motivation to irrigate their fields and neighboring farmers' intensification for irrigation. However, it may affect the adequacy of irrigation water.

As indicated in Fig. 11 below, the land productivity (output per unit irrigated area and output per unit command area) of Bilate irrigation scheme was much higher than that of the Furfuro irrigation scheme. This might be happened due to differences in irrigated field productivity during the study season because of the variation in cropping pattern, soil fertility, and willingness of farmers to invest more agricultural inputs such as fertilizers, pesticides, and herbicides, which means higher yield per



	OPUIA (US$/ha)	OPUCA (US$/ha)
Bilate Irrigation Scheme	4140.4	4510.3
Furfuro Irrigation Scheme	1781.5	1968.5

Fig. 11 Comparison of Bilate and Furfuro schemes based on land productivity

unit of land at Bilate irrigation scheme. Moreover, highly productive and marketable crops such as potato and maize were dominant crops in Bilate scheme. From this evidence, therefore, the Bilate irrigation scheme had better land productivity than Furfuro irrigation scheme.

According to Fig. 12, the result obtained for output per unit of irrigation supply and output per unit of water consumed was better in Bilate irrigation scheme than Furfuro irrigation scheme. This implied that more outputs were returned from unit irrigation water applied and water consumed from Bilate irrigation scheme than Furfuro irrigation scheme. The reason might be the irrigated crops were high value crops in Bilate irrigation scheme, better soil fertility, farmers' awareness, and motivation for irrigation. Therefore, Bilate irrigation scheme had better water productivity than Furfuro irrigation scheme.

Bilate irrigation scheme had significantly better land and water productivity than Furfuro scheme due to use of high value crops, better agricultural inputs and removal of grass cover, and sedimentation from canal systems. Hence, Bilate irrigation scheme was better performing than Furfuro irrigation scheme. Therefore, adopt the best practices learned from Bilate irrigation scheme for the Furfuro scheme. Moreover, properly maintain malfunctioned infrastructures, create WUAs and agricultural experts, and create awareness for farmers and WUAs on irrigation water management in two irrigation schemes.

Conclusion and recommendations

Conclusions

Performance evaluation of the irrigation schemes is a vital activity to pinpoint and locate the problem areas and so that prompt improvement options and then assists engineers to design new systems. Moreover, the comparative performance evaluation provides clear information on performance level of the schemes that enables to transfer best practices to take improvement measures. Therefore, the objective of this study was to evaluate the performance of the Bilate and Furfuro schemes in Silti Zone, southern Ethiopia. Two irrigation schemes were evaluated by their own merits using internal performance indicators, and a comparison was also made using external performance indicators. Three representative farmers' fields were selected at the head, middle, and tail end of each irrigation scheme.

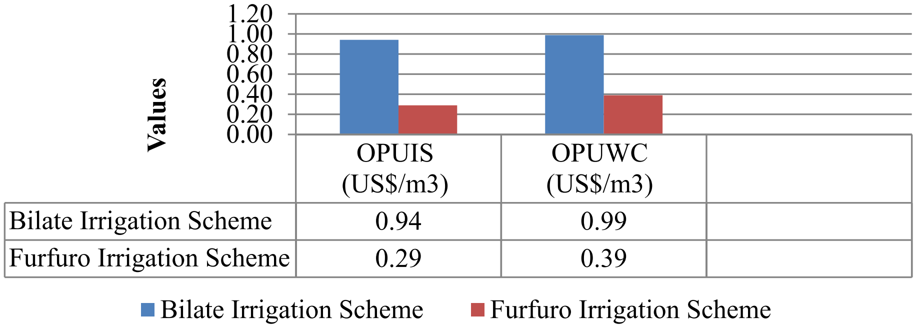


Fig. 12 Comparison of Bilate and Furfuro schemes based on water productivity

The results of application efficiencies for two irrigation schemes indicated the need for improvements in on-field water management. The water storage efficiency results of the two schemes show that the applied water did not satisfy the soil moisture deficit, therefore indicating the inadequacy of the irrigation. Moreover, the results of conveyance efficiencies and losses show that the two schemes had an unreasonable loss of irrigation water in their conveyance systems. The overall irrigation efficiencies were poor in two irrigation schemes. Generally, the results of internal performance indicators indicated that two irrigation schemes were performing inefficiently and inadequately. The main reason might be the applied irrigation water was below the crop water demand or farmers lack of awareness of different crops need different amounts of water, high sedimentation and illegal water turnout in main and secondary canals and water stagnation, grass cover in canals waterway, and widening of tertiary canals size and unreasonable losses of water in conveyance systems. But the irrigation water was distributed uniformly within the field in two schemes. The reason might be the farmers use short-length and closed-end furrows.

The results obtained for external performance indicators revealed that the applied irrigation water did not tightly satisfy the crop water demands and peak consumptive use. The reason might be poor field water management, failure in infrastructures (division boxes and flow control gates), unacceptable losses of irrigation water in conveyance systems, irrigation intensification from neighboring farmers and illegal water turnout in main and secondary canals, high water competition among farmers and at the source of Bilate irrigation scheme, and lack of awareness on water demand of crops. However, the irrigated lands were expanded in two irrigation schemes. Moreover, the results of output per unit command area were better than output per unit irrigated area in two irrigation schemes; this is evidence that there is an effect thereby expansion of the irrigated area by 27.25 ha in Bilate and 21 ha in Furfuro schemes relative to the designed area without delivering additional irrigation water. Moreover, the result of output per unit of water consumed was better than output per unit of irrigation water supply for two irrigation schemes. This is evidence that the lack of awareness to apply the crop water demand may affect the irrigated agriculture outputs.

The Furfuro irrigation scheme was better performing than Bilate irrigation scheme in terms of conveyance losses, relative water supply, and relative irrigation supply, whereas the Bilate irrigation scheme was meaningfully better performing than Furfuro irrigation schemes in terms of irrigated agriculture output and water delivery capacity. So, Bilate irrigation scheme had better performance than Furfuro irrigation scheme. The reason might be productive use of irrigation water, had better soil fertility, higher value crops were irrigated dominantly, more intensive irrigation, and better agricultural inputs in Bilate irrigation scheme. Hence, the irrigation managers in Furfuro irrigation scheme adopt the best practices learned from Bilate irrigation scheme. But two irrigation schemes need improvement measures. This study was conducted only in one irrigation season, and performance evaluation of two irrigation schemes, therefore the financial performance indicators and organizational setups, was not seen.

Recommendations

- The two irrigation schemes need proper maintenance of the division boxes and flow control gates, continuously removing sediment from the main and secondary canals and prevention of grass cover in unlined canals waterways, water stagnation in-field distribution canals, and widening of unlined canal sections.
- Encourage water users association and local agricultural experts who share water and ensure equity among users, especially during periods of water shortage.
- Create awareness to beneficiary farmers and water users' associations about field irrigation water measurements, irrigation water management strategies, scheme operation, and maintenance practices through continuous training.
- Wereda experts and DAs with water users association must plan seasonal water demand, irrigation duration, and scheduling for farmers and water association users according to the crop pattern in the scheme area and do not irrigate an area that exceeds the planned area. Thus, decisions concerning flow rate, duration, and frequency should be placed in the hands of DAs and WUAs.
- Adopt the best practices learned from Bilate irrigation scheme for the Bilate irrigation scheme; for example, use more productive crops, better agricultural inputs, removal of grass cover and sedimentation from canal systems, etc.

Abbreviations

GPS	Global Positioning System
WUAs	Water use associations
DAs	Development agents

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Authors' contributions

Corresponding author contributed by developing the research idea, designing the research methods, correcting and analyzing the data, and organizing and writing the manuscript. The other authors contributed by arranging, organizing, and advising the article starting from research idea up to manuscript full write-up. All authors reviewed the results and approved the final version of the manuscript.

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Declarations

Competing interests

The authors declare that they have no competing interests.

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