



# Performance Evaluation of Surface Irrigation System in the Case of Dirma Small-Scale Irrigation Scheme at Kalu Woreda, Northern Ethiopia

Eshetu Adane Kibret<sup>1</sup> · Abebech Abera<sup>2</sup> · Workineh Tadesse Ayele<sup>1</sup> · Neway Asrat Alemie<sup>1</sup>

Received: 5 July 2021 / Revised: 22 September 2021 / Accepted: 22 September 2021 / Published online: 12 October 2021  
© The Author(s), under exclusive licence to Springer Nature Singapore Pte Ltd. 2021

## Abstract

This study was conducted to evaluate the performance of Dirma small-scale irrigation scheme using selected performance indicators. To achieve these objectives, the primary data collected for this study were discharge measurements in the canals, measurements of water applied to the field, and soil data before and after irrigation. Besides, secondary data collected were also climatic and agronomic data, yields, command, and initial area. CROPWAT 8.0 model and Microsoft Excel were used to analyze the data. The results of internal indicators: conveyance efficiency, application efficiency, storage efficiency, and overall efficiency were 76.64%, 56.05%, 79.40%, and 43.54%, respectively, whereas the results of the external indicators: relative water supply, relative irrigation supply, water delivery capacity, irrigation ratio, the sustainability of an irrigated area, output per unit irrigated area, output per unit command area, output per unit water supply, and output per unit water consumed were 1.0, 0.95, 0.26, 0.41, 1.5, 4881.40 US\$/ha, 1896.56 US\$/ha, 1.64 US\$/m<sup>3</sup>, and 1.25 US\$/m<sup>3</sup>, respectively. There was an unfair distribution of water due to water scarcity and illegal water users as the beneficiaries responded. Those performance external indicator values indicate that there is a low water supply, the actual command area was reduced by 61% from initially designed, and some structures initially installed were becoming nonfunctional. The basis of this conclusion was frequent field observation, sustainability of an irrigated area result, and beneficiary responses about the initial and current condition of the scheme. Generally, the overall performance of the scheme is considered poor. Therefore, a gated division system, regular canal cleaning, and maintenance of broken irrigation infrastructures should be applied to mitigate the water scarcity problem.

**Keywords** Indicators · Field efficiency · Performance

## Introduction

Water is a crucial natural resource for all aspects of life, which is used for domestic, agriculture, recreation, and industrial purpose. The major portion of the water resource is used in the agriculture sector for irrigation purposes to enhance crop production. Irrigation is an artificial application of water for crops in a specified area to increase yield and production, particularly in dry climates where the rainfall is not sufficient for crop production. Therefore, optimum utilization of the available water is of paramount importance [20].

Small-scale irrigation is considered as one of the options for increasing agricultural productivity and supporting development in Sub-Saharan Africa [22]. It is characterized by the use of simple water access technologies for irrigation. For several years, Africa has advocated irrigated agriculture

---

✉ Abebech Abera  
abiti.abe@gmail.com

Eshetu Adane Kibret  
eshetu2127@gmail.com

Workineh Tadesse Ayele  
Workineh2658t@gmail.com

Neway Asrat Alemie  
newayasrat@gmail.com

<sup>1</sup> Hydraulic and Water Resources Engineering, Debre Tabor University, Debre Tabor, Ethiopia

<sup>2</sup> Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia

as a way of ensuring food safety and improving the living standards of rural people [19].

Various studies have shown that irrigation schemes improve food security and livelihoods of rural farmers in Africa [4, 11, 32, 44].

Ethiopia is one of the African countries endowed with ample water resources. According to Change [10], Ethiopia has 12 river basins with an annual runoff volume of 124 billion meter cube (BMC) of water and an estimated range of 2.6 to 30 BMC groundwater potential. The irrigation potential is also estimated at 5.3 Mha from 15 Mha of the total cultivated area. The irrigated area of the country is 640,000 ha. Of these 120,000 ha using rainwater harvesting, 383,000 ha from small-scale irrigation, and 129,000 ha from medium and large-scale irrigation systems [3], [10]. Lambisso [24] revealed that one of the best alternatives to consider for reliable and sustainable food security is expanding irrigation development on various scales, through river diversion, constructing micro dams, and water harvesting structures.

The majority population of Ethiopia is dependent on rain-fed agricultural production for its livelihood. The major problems associated with rain-fed agriculture in the country are a high degree of rainfall variability and unreliability. In this regard, sustainable food production through an optimal development of water resources, in conjunction with the development of land, depends on the method of irrigation considered (FAO, 2003).

As IWMI [21] reported, Ethiopia faces four key technical, socioeconomic, institutional, and environmental challenges that must be overcome to meet irrigation development: behind schedule scheme delivery, low-performance of the schemes, constraints on scale-up of irrigation projects, and protecting irrigation development sustainability.

Evaluating the performance of irrigation systems was assist to distinguish whether the targets and objectives of the irrigation projects are met or not [41]. The performance indicator study shows that the evaluation of the actual performance of the irrigation system should depend on an accurate hydrological water balance over the area considered [20].

The performance of many agriculture systems are significantly below their potential due to poor design, construction, operation, maintenance, and inefficient irrigation water management [30].

According to Pereira [33], field evaluation plays a fundamental role in improving irrigation systems. International Water Management Institute (IWMI) developed two types of indicators to evaluate irrigation systems: internal and external (productivity) indicators. The main objective of this study was going to evaluate the performance of the irrigation scheme using selected internal and external indicators. The selection of those indicators was based on the material and data availability for data collection and analysis. The major problems of the study area are that the actual irrigated

land is too low as compared with the planned area, water control structures constructed in the scheme are not fully operational, and the scheme has not been fully functional as expected.

## Materials and Methods

### Description of the Study Area

The irrigation scheme is located mainly at Kalu Woreda in the South wollo zone from Amhara National Regional State (ANRS). The altitude of the woreda ranges between 1400 and 2800 m above mean sea level. The project area is accessed through asphalt road 20 km from Kombolcha to Harbu and 6 km from Harbu to the proposed project area is a gravel road and constructed by the Commission for Sustainable Agriculture and Environmental Rehabilitation in the Amhara Region (Co-SAERAR) in the year 1994 E.C. The rainfall distribution is a bimodal type, contains “Belg” and “Kiremet” season, but the Belg rainfall is very variable in commencement and amount (Fig. 1).

### Materials Used

Auger and core samplers were used to collecting disturbed and undisturbed soil samples, respectively. The sensitive balance was used to measure the weight of the soil sample and a smartphone camera to capture necessary photos during observation and field measurement. Ninety-degree V-notches weirs were used to measure the discharge of the branch off-take canals and applied water to the field. Floating objects and a stopwatch were used for measuring canal water flow velocity. A tape meter was used to measure different dimensions. Global Positioning System (GPS) was used to capture different coordinate points of the scheme.

### Method of Data Collection

Data were collected from both primary and secondary sources in collaboration with agronomists, kebele development agents (Das), and some farmers who were consulted about the irrigation scheme condition.

Primary data were collected through field observations and field measurements. Secondary data were gathered from different sources like reports, documents kept by the Woreda Agricultural Office, literature, and personal visits at the scheme.

### Method of Data Analysis

For data analysis and manipulation activities, CROPWAT 8.0 and Microsoft Excel were used. Arc GIS and Google

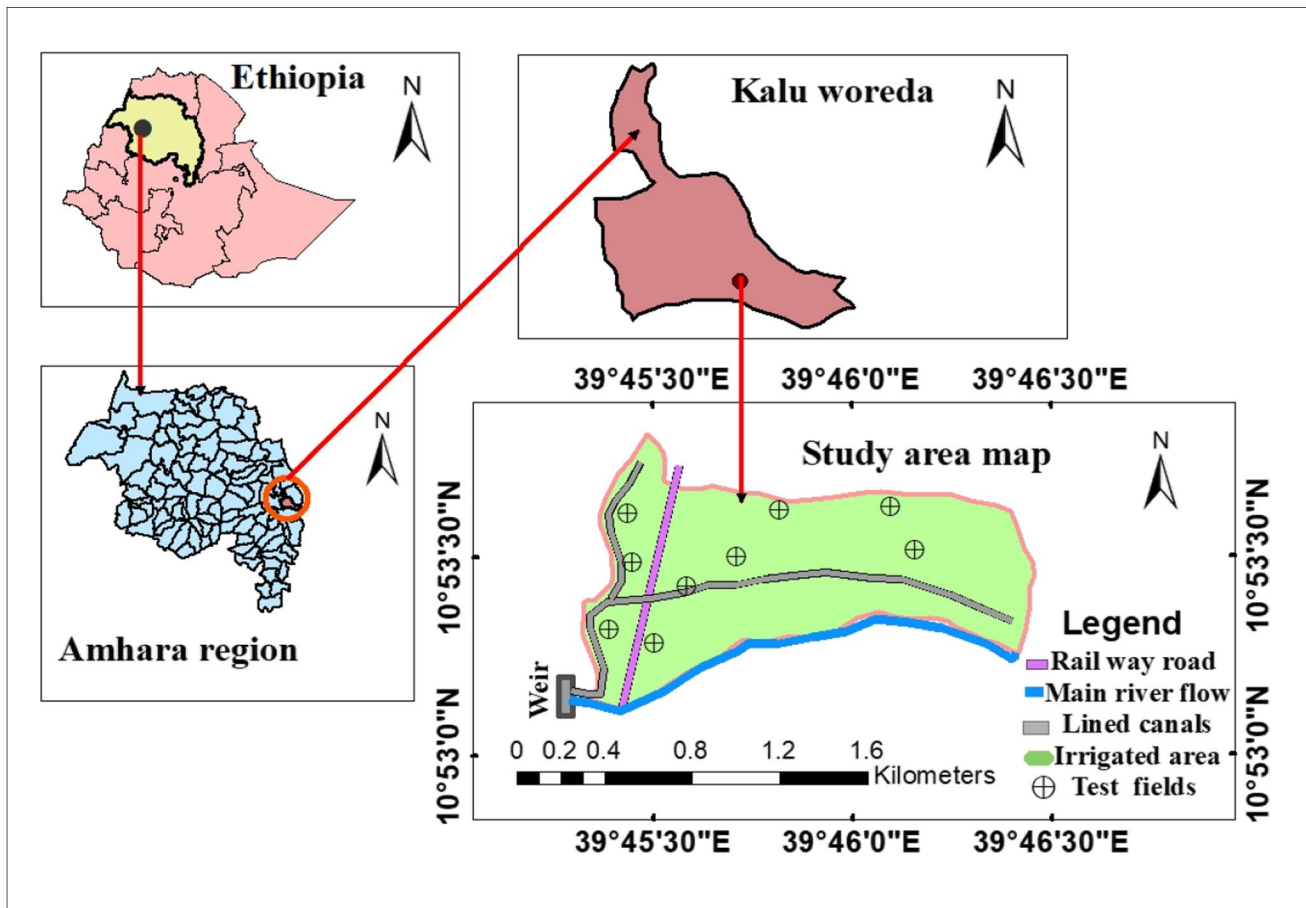


Fig. 1 Map of the study area

Earth were used to delineate the map of the study area and the layout of the irrigation schemes through digitization.

The soil particle size composition of each particle was analyzed using hydrometer analysis in the laboratory and based on the percentage of each particle composition, the soil textural class was determined by the USDA soil textural triangle method [8]. Soil moisture content was determined by gravimetric moisture content oven drying the soil samples taken from preselected fields by 30 cm depth interval up to 90 cm from the top at 105 °C for 24 h. The average depth of water stored to the root zone (mm) determined by gravimetric soil moisture content in each sample on a weight basis infraction ( $\theta_w$ ) was calculated using the equation [15]:

$$\theta_w = \frac{W_w - W_d}{W_d} * 100 \tag{1}$$

where  $\theta_w$  = soil water content on a dry weight basis,  $W_w$  = wet weight of the soil (g)  $W_d$  = dry weight of the soil (g).

The gravimetric moisture content on volume base was estimated as the product of gravimetric content and bulk density:  $\theta_v = \theta_w * B_d$ .

$$D_s = \sum_{i=0}^n \frac{(\theta_{vAI} - \theta_{vBI})}{100} i * D_i$$

where  $D_s$  is the average depth of water stored to the root zone (mm);  $\theta_{vAI}$  and  $\theta_{vBI}$  are moisture content of the  $i$ th soil layer after and before irrigation on an oven-dry volume basis (%), respectively;  $D_i$  is the thickness of the  $i$ th soil layer (m); and  $n$  is the number of layers in the root zone.

Field capacity (FC) and permanent wilting point (PWP) were determined using pressure plate apparatus in the laboratory and the soil moisture content at 0.33 bar suction was for FC and that at 15 bar was for PWP by taking three composite soil samples from each stratum (head, middle, and tail). Based on field capacity (FC) and permanent wilting point (PWP), total available water (TAW) amount in the soil was determined which is the total amount of water a crop can extract from its root zone.

$$TAW = 1000 * (\theta_{fc} - \theta_{pwp}) * Z_r \tag{2}$$

where  $TAW$  the total available soil water in the root zone (mm),  $\theta_{fc}$  the water content at field capacity ( $m^3/m^3$ ),  $\theta_{pwp}$

the water content at wilting point ( $\text{m}^3/\text{m}^3$ ), and  $Z_r$  effective root depth of crop (m).

Bulk density refers to the compactness of soil and which was determined using undisturbed soil samples with a core sampler volume of  $98.125 \text{ cm}^3$  at the interval of 30 cm each. The samples were weighed and placed in an oven and dried at  $105 \text{ }^\circ\text{C}$  for 24 h. The dry bulk density ( $Bd$ ) was computed by dividing the oven-dry mass of the soil sample ( $Md$ ) to a known volume of core sampler ( $Vc$ ) [6] as:

$$Bd = \frac{Md}{Vc} \quad (3)$$

where  $Bd$  is the bulk density of the soil ( $\text{g}/\text{cm}^3$ ),  $Md$  is the dry weight of the soil (g),  $Vc$  is the volume of core samplers ( $\text{cm}^3$ ), i.e.,  $Vc = A * h$ ,  $A$  is the area of the core ( $\text{cm}^2$ ),  $A = \frac{\pi d^2}{4}$ , because the core samplers were circular.

$h$  is the height of the core (cm) and  $d$  is the internal diameter of the core (cm).

### Determination of Irrigation Water Requirement for Crop

To estimate the crop water requirements, irrigation water requirement (IWR) and establish irrigation scheduling of the major crops grown in the scheme, CROPWAT 8:0 model was used [16]. Penman–Monteith method was selected to calculate the reference crop evaporation ( $ET_o$ ) as indicated in Eq. 4.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (4)$$

where  $ET_o$  is the reference evapotranspiration ( $\text{mm day}^{-1}$ );  $R_n$  is net radiation at the crop surface ( $\text{MJ m}^{-2}\text{day}^{-1}$ );  $G$  is soil heat flux density ( $\text{MJ m}^{-2}\text{day}^{-1}$ );  $T$  is air temperature ( $^\circ\text{C}$ );  $u_2$  is wind speed ( $\text{ms}^{-1}$ );  $e_s$  and  $e_a$  are saturation and actual vapor pressures, respectively (kPa);  $\Delta$  is slope vapor pressure curve ( $\text{kPa } ^\circ\text{C}^{-1}$ ); and  $\gamma$  is psychrometric constant ( $\text{kPa } ^\circ\text{C}^{-1}$ ).

Then the crop water requirement ( $CWR$ ) was estimated by subtracting effective rainfall from  $ET_c$  [13] as:

$$ET_c = ET_o \times k_c \quad (5)$$

$$\begin{aligned} CWR &= ET_c - P_e \text{ if } ET_c > P_e \\ \text{otherwise } CWR &= 0, \text{ rainfall is enough} \end{aligned} \quad (6)$$

Hence, the gross irrigation requirement was determined by first measuring the field application efficiency and then dividing the net irrigation requirement ( $CWR$ ) by the efficiency obtained.

$$R_g = \frac{R_n}{E_a} \quad (7)$$

where  $R_n$  is the net irrigation requirement which is the same as  $CWR$ ,  $R_g$  is the gross irrigation requirement, and  $E_a$  is the field irrigation application efficiency. Data for major crops grown in the study areas including growing stages and stage lengths (days), crop coefficients ( $k_c$ ), rooting depths ( $Z_r$ ), depletion levels ( $P$ ), and yield response factors ( $k_y$ ) were obtained from the report document and interview [2, 14].

### Irrigation Scheduling

The method of deciding when to irrigate and how much water to add to the field per irrigation is irrigation scheduling. To calculate the irrigation interval, the first readily available water was calculated from the total water available and the management of permissible depletion. The part of the total water available that is most easily extracted by the plant roots without causing stress is readily available water.

$$RAW = P * TAW \quad (8)$$

where  $RAW$  = the readily available soil water in the root zone (mm),  $P$  = an average fraction of total available soil water ( $TAW$ ) that can be depleted from the root zone before moisture stress (reduction in ET) occurs (0–1) water depletion fraction/management allowable depletion (%) and then the irrigation interval was calculated as:

$$Intervals(\text{days}) = \frac{RAW}{CWR} \quad (9)$$

### Internal Performance Indicators

The internal indicators examine the technical or field performance of a project by measuring how close an irrigation event is to an ideal one.

#### Conveyance Efficiency (CE)

The conveyance efficiency of the main, secondary, and field canals was measured by the inflow outflow method to determine the conveyance loss [1].

$$C_e = \frac{V_o}{V_i} \quad (10)$$

where  $C_e$  is the conveyance efficiency;  $V_i$  and  $V_o$  were the inflow diverted into the canal and outflow from the canal/in specified canal reached length ( $\text{m}^3/\text{s}$ ) determined by floating at lined canals and V-notch method at unlined canals. The surface velocity,  $V_s$  and mean flow velocity as:  $V_s \left( \frac{\text{m}}{\text{s}} \right) = \frac{L}{t_{av}}$

$$Vm = \frac{0.85 * L}{tav} \tag{11}$$

The cross-sectional area was calculated as:  
 $A = (b * y)$ , for rectangular cross-section  
 $A = \frac{(a+b)}{2} * y$ , for the trapezoidal cross-section  
 where  $A$  — cross-sectional area of flow (m<sup>2</sup>),  $a$  — top width of the canal (m),  $b$  — base width of the canal (m), and  $y$  — depth of water in canal (m).

Finally, discharge can be calculated by the area velocity method,  $Q = V * A$  that is:

$$Q \left( \frac{m^3}{s} \right) = \frac{0.85 * L * A}{t} \tag{12}$$

Then the general conveyance efficiency of the scheme was calculated by weight as:

$$Ec = \frac{Ecm * Lm + Ecs * Ls + Ect * Lt}{Lm + Ls + Lt} \tag{13}$$

where  $Ecm$  is the conveyance efficiency of the main canal;  $Ecs$  is the conveyance efficiency of the secondary canal;  $Ect$  is the conveyance efficiency of the tertiary canal; and  $Lm$ ,  $Ls$ , and  $Lt$  are the lengths of the main, secondary, and tertiary, respectively.

**Application Efficiency**

The application efficiencies ( $Ea$ ) of irrigation at the selected field is the ratio of the depth of the water stored in the root zone of the soil ( $Ds$ ) to the depth of water applied into the fields ( $Df$ ) determined by the V-notch weir.

$$Ea = \frac{Ds}{Df} * 100 \tag{14}$$

where  $Ea$  is application efficiency (%),  $Ds$  is the average depth of water stored in the root zone (mm), and  $Df$  is the average depth of water applied to the field (mm).

The field application water depth was measured by 90° V-notch weirs which were installed at the entrance of the test plot and frequent readings were taken when the farmers irrigate the test plot used to measure the discharge entering into the field (sample) plot. The triangular or V-notch weir is preferable to other weirs for the measurement of low and widely variable flows [31]. The measured water depth was changed into its respective discharge by using the V-notch formula [39].

$$Q = C \frac{8}{15} \frac{\sqrt{2gtan\frac{\theta}{2}H^5}}{2} \tag{15}$$

The most common angle of the notch is 90°, for which, with a value of  $C$  about 0.6–0.62, the approximate formula for discharge is  $Q = 2.5H^{2.5}$  [31].

The depths of water applied to the field were estimated as:

$$Df = \frac{Q * t * 1000}{a}$$

where  $Df$ =the depth of water applied into the field (mm),  $Q$ = discharge (m<sup>3</sup>/s) obtained from V-notch formula,  $t$ =inflow time (s), and  $a$ =irrigated area (m<sup>2</sup>).

**Storage Efficiency**

It is the ratio of the quantity of water stored in the root zone during an irrigation event determined by gravimetric moisture content laboratory to water desired in the root zone before irrigation.

$$Es = \frac{Ds}{Wd} * 100 \tag{16}$$

where  $Es$  is storage efficiency (%),  $Ds$  is water stored in the root zone (mm), and  $Wd$  is water desired to be stored in the root zone before irrigation (mm) computed using Michael [26] equation:

$$Wd = \sum_{i=0}^n \frac{(MFC - MBI)}{100} Ai * Di$$

where  $MBI$ = $i$ th layer of volumetric moisture content before irrigation (%),  $MFC$ = $i$ th layer of volumetric moisture content at field capacity (%),  $Ai$ =bulk density of the soil in the  $i$ th layer,  $Di$ = $i$ th layer of crop root depth (mm), and  $n$ =number of layers in the root zone.

**Deep Percolation Ratio (DPR)**

The runoff ratio was normally being considered for this particular study as zero as the farmers’ are using furrows whose tail ends are closed. However, the deep percolation ratio was computed as the ratio of the percolated water beyond the root zone to the volume of water applied to the field was computed using the formula [18]:

$$DPR = 100 - Ea - RR \tag{17}$$

where  $DPR$  is deep percolation ratio (%),  $Ea$  is application efficiency, and  $RR$  is runoff ratio ( $RR = 0$ ).

**Overall Scheme Efficiency**

Overall scheme efficiency was calculated as the product of conveyance and application efficiency.

$$Ep = Ec * Ea \tag{18}$$

where  $Ep$  is overall scheme efficiency (%),  $Ec$  is conveyance efficiency (%), and  $Ea$  is application efficiency (%).



## External Performance Indicators

The external or comparative performances of the scheme were evaluated using some selected comparative indicators.

## Water Delivery Indicators

The selected indicators used for the evaluation of water delivery indicators are relative water supply (RWS), relative irrigation supply (RIS), and water delivery capacity (WDC). Both RWS and RIS are given some indication about the condition of water abundance or scarcity and how tightly supply and demand are matched [41].

### Relative Water Supply

According to Molden et al. [30], the relative water supply is the ratio of total annual water supplied (irrigation plus rainfall) to the annual crop water demand (determined with the CROPWAT model).

$$\text{Relative water supply} = \frac{\text{Total water supply}}{\text{Crop water demand}} \quad (19)$$

where *Total water supply* = surface diversion plus effective rainfall ( $\text{m}^3$ ); *Crop water demand* = potential ET or the ET under well-water conditions for each crop ( $\text{m}^3$ ).

### Relative Irrigation Supply

Relative irrigation supply (RIS) is the ratio of annual irrigation supply (which excludes rainfall) to annual irrigation demand. This indicator is useful to assess the degree of irrigation water stress/abundance/irrigation demand [30]. Values of relative irrigation supply (RIS) higher than one indicate that excess irrigation water is being supplied. The indicators are estimated as per the equations below.

$$\text{Relative irrigation supply} = \frac{\text{Irrigation supply}}{\text{Irrigation demand}} \quad (20)$$

where *Irrigation supply* = only the surface diversion for irrigation ( $\text{m}^3$ ), *Irrigation demand* = the crop ET less effective rainfall ( $\text{m}^3$ ).

The total net crop water requirement/demand/for the season was determined as:

$$\begin{aligned} \text{CWR} = & \text{CWR}_{\text{onion}} * \left( \frac{\text{Aonion}}{\text{Atotal}} \right) + \text{CWR}_{\text{tomato}} * \left( \frac{\text{Atomato}}{\text{Atotal}} \right) \\ & + \text{CWR}_{\text{teff}} * \frac{\text{Ateff}}{\text{Atotal}} + \text{CWR}_{\text{pepper}} * \left( \frac{\text{Apepper}}{\text{Atotal}} \right) \end{aligned}$$

With the same computation procedures, the total net irrigation requirements of the season were determined.

## Water Delivery Capacity

Water delivery capacity is the ratio of the amount of actual water supplied by the system relative to the amount of irrigation water intended. It was measured by comparing the volume of water delivered to the expected volume (design) of water to be delivered.

It demonstrates improvements in service quality for water users and quantifies the uniformity and equity of water delivery [7]. The water delivery capacity indicator was calculated as:

$$\text{WDC} = \frac{Q_a}{Q_i} * 100 \quad (21)$$

where *WDC* is the water delivery capacity (%), *Q<sub>a</sub>* is actually delivered discharge of water ( $\text{m}^3/\text{s}$ ), and *Q<sub>i</sub>* is designed (intended) discharge of water to be delivered ( $\text{m}^3/\text{s}$ ).

## Physical Indicators

Physical indicators are related to changing or losing irrigated land in the command area for different reasons. The selected indicators used for the evaluation of physical performance are irrigation ratio (*IR*) and sustainability of irrigated area (*SIA*).

Irrigation ratio (*IR*) is an indicator used to evaluate the degree of utilization, in which the land available for irrigation is also a useful indicator of whether factors are contributing to under irrigation of the command area. Irrigated area sustainability (*SIA*) tells us that the area under irrigation is contracting or expanding as compared to the area initially irrigated.

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

$$\text{Sustainability of irrigated area (SIA)} = \frac{\text{Currently irrigable area}}{\text{Initially irrigated area}} \quad (23)$$

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 designed command area, *Currently irrigable area* is the area that currently can be irrigated (ha), and *Initially irrigated area* is the designed/nominal/irrigable area (ha).

## Agricultural Performance Indicators

The basic indicators of agricultural performance were related to crop production as output while inputs were land and water.

### Output per Unit Irrigated Area (Birr/ha)

In the irrigation season, it was measured as the overall output value per harvested area.

$$OPUIA = \frac{\text{Seasonal value of production}}{\text{Irrigated cropped area}} \quad (24)$$

### Output per Unit Command Area (Birr/ha)

This is another measure of land productivity that quantifies the amount of output obtained per unit irrigable area of command.

$$OPUCA = \frac{\text{Seasonal value of production}}{\text{Command area}} \quad (25)$$

### Output per Unit Irrigation Water Supply (Birr/m<sup>3</sup>)

Water productivity indicators are calculated as the total value of production per unit of water diverted from the source to the command area throughout the irrigation season [30].

$$OPUIS = \frac{\text{Seasonal value of production}}{\text{Diverted irrigation supply}} \quad (26)$$

### Output per Unit Water Consumed (Birr/m<sup>3</sup>)

Consumed water is the actual evapotranspiration or process consumption from only irrigated crops (ET); it excludes other losses and water depletion from the hydrological cycle.

$$OPUWC = \frac{\text{Seasonal value of production}}{\text{Volume of water consumed by crop}} \quad (27)$$

where *Production* = the output of the irrigated area in terms of the gross or net value of production measured at local or world prices, *Irrigated cropped area* = the sum of the areas under crops during the period of analysis, *Command area* = the nominal or design area to be irrigated, *Diverted irrigation supply* = the volume of surface irrigation water diverted to the command area, and *Volume of water consumed by ET* = the actual evapotranspiration of crops.

The need for calculation of so many indicators was limited by those indicators based on the scope of the study and limited data. The scope of this study was concerned with the performance evaluation of the scheme, with special attention to the evaluation of the current operation rules in terms of matching supply with demand, adequacy, output, scheme efficiency and sustainability, and delivery to various parts of the system.

## Results and Discussions

### Soil Textural Class, Bulk Density, and PH Value

According to the USDA SCS Soil textural triangle, the textural class for Dirma irrigation scheme was clay, clay loam and sandy loam that were dominant at head reach, middle reach, and tail reach of the canal, respectively. 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 1.18, 1.25, and 1.19 g/cm<sup>3</sup>, respectively. The result implies the top surface soil had lower bulk density than the subsurface and soil with textural class clay loam which was more compacted than clay and sandy loam as indicated in Table 1. Miller and Donahue [27] recommended soil bulk density below 1.4 g/cm<sup>3</sup> for clays and 1.6 g/cm<sup>3</sup> for sands to get better plant growth. The current results at the head, middle, and tail reach were in the recommended range. The average soil pH was 5.31 to 5.66 for the three canal reaches of the irrigation scheme as indicated in Table 1. The pH value of the scheme was in line with Liu and Hanlon [25] which was reported as a pH range from 5.5 to 7.0 is suitable for most vegetable crops than acidity.

### Field Capacity, Permanent Wilting Point, and Total Available Water

The soil moisture content at field capacity (FC) varied from 17.89 to 31.87%, permanent wilting point (PWP) 9.25 to 19.24%, and total available water (TAW) 86.4 to 133.6 mm/m with the interval of 30 cm up to 90 cm soil depth was analyzed as indicated the results in Table 2. The relative magnitude of moisture content at field capacity (FC) and permanent wilting point (PWP) of the soil depends on its textures and structures. In general, the results of FC, PWP, and TAW were found to be in the acceptable range given by FAO [17].

The reference crop evapotranspiration (*ET<sub>o</sub>*) and effective rainfall of the study area were computed and mean monthly *ET<sub>o</sub>* values were much higher than that of effective rainfall except in July and August. As a result, extra water is required to fulfill the evapotranspiration demands of the scheme as indicated in Fig. 2. Similarly, the mean annual effective rainfall of the area, available for the plant, was 714.5 mm with mean monthly values.

### Crop Water and Irrigation Water Requirements

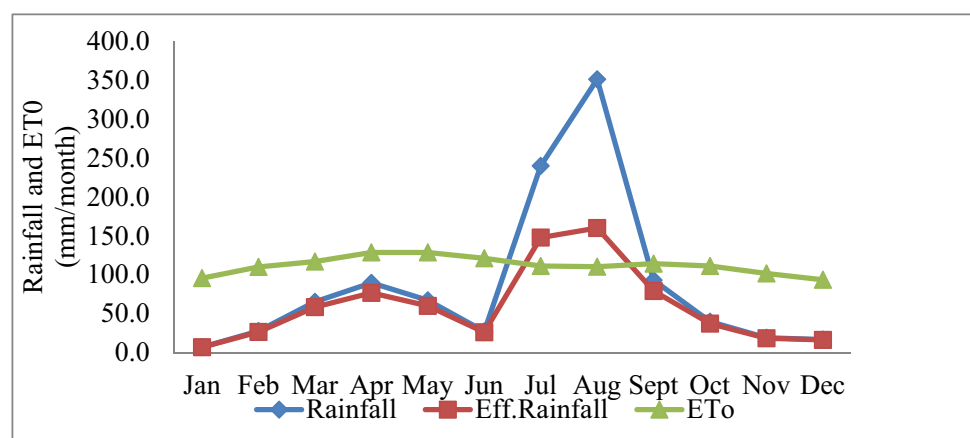
Crop water and irrigation water requirements were calculated using CROPWAT 8.0 model based on Eqs. 4, 5, and 6 by using crop characteristics data and soil description as

**Table 1** Soil textural class, bulk density, and pH value

Farmers field	Soil depth cm	Particle size distributions %			<i>Bd</i> g/cm <sup>3</sup>	pH	Soil texture class
		Sand	Silt	clay			
Head reach	0–30	21	31	48	1.21	5.48	Clay
	30–60	28	29	42	1.28	5.49	Clay
	60–90	33	26	41	1.05	5.54	Clay
Average					1.18	5.5	
Middle reach	0–30	39	33	28	1.39	5.65	Clay loam
	30–60	41	31	29	1.17	5.66	Clay loam
	60–90	40	33	27	1.18	5.68	Clay loam
Average					1.25	5.66	
Tail reach	0–30	55	29	16	1.24	5.28	Sandy loam
	30–60	55	26	18	1.02	5.3	Sandy loam
	60–90	53	27	20	1.31	5.34	Sandy loam
Average					1.19	5.31	

**Table 2** Soil moisture at FC, PWP, and TAW of the irrigation scheme

Farmers field	Soil depth cm	FC %	PWP %	TAW %	TAW mm/m	TAW mm
Head reach	0–30	31.87	19.24	12.63	126.3	37.89
	30–60	31.75	19.18	12.57	125.7	37.71
	60–90	31.65	19.08	12.57	125.7	37.71
Average		31.76	19.17	12.59	125.9	37.77
Middle reach	0–30	28.35	14.99	13.36	133.6	40.08
	30–60	28.28	14.95	13.33	133.3	39.99
	60–90	28.24	14.92	13.32	133.2	39.96
Average		28.29	14.95	13.34	133.37	40.01
Tail reach	0–30	18.23	9.46	8.77	87.7	26.31
	30–60	18.19	9.32	8.87	88.7	26.61
	60–90	17.89	9.25	8.64	86.4	25.92
Average		18.1	9.34	8.76	87.6	26.28

**Fig. 2** Mean monthly rainfall, effective rainfall, and reference evapotranspiration

input for the major irrigated crops grown in the irrigation scheme and this model result was used as input for irrigation water delivery performance (Table 3).

### Irrigation Scheduling

The irrigation interval in the scheme was irregular depending on the availability of water; condition of crop and growth



**Table 3** 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
Onion	181.8	391.1	209.3
Tomato	231.9	500.9	269
Teff	105.9	288.7	182.8
Pepper	217.7	431.2	213.5

**Table 4** Average conveyance efficiency of canal systems

Canal part	Conveyance efficiency (%)	Length (m)	Remark
Lined main canal	95.43 above [37], 88.7%	650	Good
Unlined secondary canal 1	77.37 above [28], 70%	200	Good
Unlined secondary canal 2	73.19 above [28], 70%	550	Good
Lined secondary canal 3	72.67 below [37], 88.7%	1930	Poor
Lined secondary canal 4	77.70 below [37], 88.7%	940	Poor
Unlined tertiary canal	69.04 below [28], 70%	500	Poor

stage of the crop the interval varies between 7 and 10 days throughout the growing season. The next irrigation turn will be repeated after all the groups have fully irrigated their farm.

During this time some farmers irrigate their farms by rent pumping 40 ETB per hour of pumping to achieve better crop production; the existed irrigation interval was longer than the farmers required duration.

## Internal Performance Indicators

### Conveyance Efficiency

Conveyance efficiency associated with main, secondary, and tertiary canals of the systems was computed using Eq. 10 considering the total flow delivered by the conveyance system and total inflow into the system as shown in Table 4. The corresponding discharge lost was estimated 0.02 l/s/m from lined main canal, 0.05 l/s/m and 0.06 l/s/m from unlined secondary canals, 0.04 l/s/m and 0.06 l/s/m from lined secondary canals, and 0.03 l/s/m from unlined tertiary canal. Only the lined main canal was in the acceptable range when the results were compared to Renault et al. [35] which was about 10 to 15% of loss

of water in the canal is admitted. The main causes of high water loss or low conveyance efficiency were due to sedimentation and growing weeds, silting with soil and other debris, cracking and breaking lined canals, overflowing in an unlined canal, none functional of all flow control gates, unauthorized water turnouts, and illegal water abstractions.

Overall conveyance efficiency of the scheme is 76.64%

### Application Efficiency

The estimated application efficiency of selected fields at the irrigation scheme was 59.75%, 56.43%, and 51.97% at the head, middle, and tail reach, respectively, with an average application efficiency of the scheme 56.05%. The average values of application efficiencies of the three reaches were within the ranges indicated in many kinds of literature reported for surface irrigation.

Food and Agricultural Organization (FAO) [15] reported the average application efficiency for surface irrigation in the range of 50 to 60%. Savva and Frenken [36] recommended 50 to 70% for properly designed furrow irrigation.

### Storage Efficiency

Mean water storage efficiency ( $E_s$ ) computed using Eq. 16 in the selected fields at the head, middle, and tail-end water users was 86.65%, 75.92%, and 75.61%, respectively, with the average storage efficiency of the scheme was 79.4%. The storage efficiency of all reaches was generally very low compared to the storage efficiency of Raghuwanshi and Wallender [34] of 87.5%.

### Deep Percolation Ratio

As Eq. 17 in Dirma small-scale irrigation scheme, deep percolation ratio of the farmers varied from 40.25% at the head and 43.57% at the middle reach and 48.03% at tail reach, 43.95% as average deep percolation ratio. In the scheme, there is a high deep percolation ratio which indicates over-irrigation.

### Overall Irrigation Efficiency of the Scheme

In this study, the overall efficiency of the irrigation scheme was 43.54% which is poor according to FAO [15]; a scheme irrigation efficiency of 50–60% is good, while a scheme irrigation efficiency of below 50% is considered to be poor (Table 5).

**Table 5** Summary of internal process indicators result

Internal indicators	The efficiency of the scheme (%)
Conveyance efficiency	77.68
Application efficiency	56.05
Storage efficiency	79.40
Deep percolation ratio	43.95
Overall efficiency	43.54

## External Performance Indicators

### Irrigation Water Delivery Performance

**Relative Water Supply** The calculated value of the relative water supply indicator was 1.0. A similar result was reported by Wondatir [43], at Jari small-scale irrigation scheme which was 1.0.

As the result shows, the total water supplied was sufficient for the demand for the crop water; however, it could not irrigate additional farmland.

**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 0.95 less than one which means that the diverted irrigation supply was insufficient for the irrigation demand of the crop.

The result indicated that the water would not irrigate additional irrigable land even from currently irrigated area tail users faced water scarcity from late May through early June.

**Water Delivery Capacity** The water delivery capacity was determined using Eq. 21 which based on the designed amount of water was 0.2 m<sup>3</sup>/s from the design document and the actual water delivered through the main canal is 0.053 m<sup>3</sup>/sec. The actual volume of water delivered to the main canal is much less than the designed discharge that means the result of *WDC* was 0.26. The result indicates that

the capacity of the canal is a constraint to meet the maximum crop water requirement due to poor management of the scheme and reduction of flow velocity.

### Physical Indicators

The irrigation scheme of command area, initial irrigated area, and currently irrigated areas was 231 ha, 60 ha, and 89.75 ha, respectively. The irrigation ratio and sustainability of irrigated areas were calculated using Eqs. 22 and 23, respectively.

### Irrigation Ratio

The irrigation ratio of the scheme was 0.39 which means 39% of the command area was currently under irrigation and about 61% of the command area was not under irrigation during the study period. The main reasons for this were competition due to the increasing number of water users of neighboring woreda and kebeles upstream of the scheme diversion headwork, construction of highway road across the scheme, and lack of irrigation infrastructures at the scheme.

### Sustainability of Irrigated Area

The scheme's calculated sustainability value for the irrigated area was 1.5 higher than the unit, which suggests irrigated area expansion and would mean more sustainable irrigation than what was initially irrigated. The result was nearly identical with Kassa [23] result, at Tigray, Ethiopia (Mychew small-scale irrigation scheme) which was 1.7.

### Irrigated Agriculture Performance Indicators

Under agriculture performance, land and water productivity indicators were analyzed using irrigation supply/season 267,940 m<sup>3</sup>, crop water consumed/season 349,819 m<sup>3</sup>, command irrigable area 231 ha, and total income of the scheme 438,106.01 US\$ (Table 6).

**Table 6** Irrigated crop type, yields, and output production values of the scheme

Crop type	Area (ha)	Yield (Ql/ha)	Total yield (Ql)	Unit price (Birr/Ql)	Total output (Birr)	Total income (US\$)
Onion	10.5	125	1312.5	1800	2,362,500	66,648.99
Tomato	24.25	220	5335	1000	5,335,000	150,506.81
Teff	35	11	385	3200	1,232,000	34,756.21
pepper	20	60	1200	5500	6,600,000	186,194.00
Total	89.75	416	8232.5	11,500	15,529,500	438,106.01

Ql, quintal; 1 Ql= 100 kg and 1 US\$ = 35.4469 Ethiopian Birr rate, August 2020

## Land Productivity Indicators

Under land productivity issues, output per unit area irrigated and output per unit command area performance indicators were analyzed using Eqs. 25 and 26. The finding of output per unit area irrigated was 4881.40 US\$/ha which shows that the scheme has better value than kinds of the kinds of literature [42] at Wosha irrigation scheme which was 4213.97 US\$/ha, Moges [29] result the output per unit irrigated area was 4,306.76 US\$/ha, 2,852.77 US\$/ha as reported by Shiberu et al. [41] and lower than Tesfaye et al. [42] at Werka irrigation scheme reported 5840.34 US\$/ha. A similar result also was reported by Degirmenci et al. [12] who found the output per irrigated area was varied between 308 and 5771 US\$/ha for twelve irrigation schemes found in the Southeastern Anatolia Project.

The output per unit command area result of the scheme was 1896.56 US\$/ha higher than the results of 709 US\$/ha reported by Şener et al. [38] and 1,278.59 US\$/ha reported by Shiberu et al. [41]. However, the calculated value was smaller than values of 4,746 US\$/ha at Selamko [40] and 2,852.77 US\$/ha at Haleku small-scale irrigations scheme [41].

## Water Productivity Indicators

The outputs per unit irrigation supply showed the revenue from the agricultural output for each meter cube of irrigation water supplied (Eq. 27). The outputs per unit irrigation supply of the scheme was 1.64 US\$/m<sup>3</sup> which lies in the range from 0.03 to 2.21 US\$/m<sup>3</sup> according to Cakmak [9], where the study was conducted on sixty irrigation schemes found in Kızılırmak Basin, Turkey. However, the finding was higher than the Golda irrigation scheme reported by Moges [29] which is 1.42 US\$/m<sup>3</sup> and 0.47 US\$/m<sup>3</sup> and 0.2 US\$/m<sup>3</sup> obtained from Jari and Aloma schemes, respectively, reported by Wondatir [43]. A higher value of this indicator indicates that there is a lower irrigation supply to the command area.

The output per unit of water consumed is used to describe the return on the water consumed by the crop (Eq. 28). This indicator gives due attention to the water consumed by the scheme and tells us how water is efficiently utilized by the scheme from an economic point of view. The values for this indicator were found to be 1.25 US\$/m<sup>3</sup> and it was in the range of 0.15–1.55 US\$/m<sup>3</sup> as reported by Cakmak [9].

This result shows that the water use efficiency is better than the Selamko irrigation scheme which was 1.15 US\$/m<sup>3</sup> as Shenkut [40] reported.

## Conclusions

Internal performance indicators such as conveyance efficiency, field application efficiency, storage efficiency, deep percolation ratio, and overall efficiency of the scheme were computed. Under external performance indicators, water delivery performance, physical performance, and agricultural performance were estimated. The scheme has a 650 m length of rectangular lined main canal which providing water to two unlined and two lined secondary canals with few direct tertiary canals. From this lined concrete canal, the average conveyance efficiency was 95.43% whereas the overall conveyance efficiency of the scheme was 76.64%. The result shows that there was high water loss due to the absence of flow control gates, lack of frequent canal cleaning and maintenance, compaction of seepage lines, and protection rules from canal breaching.

The average field application efficiencies of the scheme are 56.05% which is good as compared with an application efficiency of 50–70% for furrow irrigation observed in other African countries. Similarly, the mean value of storage efficiency of the scheme was 79.4% low compared to the storage efficiency of 87.5%. The overall efficiency of the scheme was also 43.54% which was poor. The relative water supply was sufficient, whereas relative irrigation supplies were insufficient beyond the crop demand.

The results of performance concerning land and water productivity output per unit irrigated area, output per unit command area, output per unit irrigation supply, and output per unit water consumed were evaluated. The main factors of which were the shortage of water, illegal water abstractions, market problems, and crop damage by insects and diseases.

**Data Availability** The required data collected for analysis are included in the manuscript. The corresponding author is ready to clarify the data and provides all the necessary data set as per the request.

## Declarations

**Ethics Approval and Consent to Participate** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study.

**Conflict of Interest** The authors declare no competing interests.

## References

1. Abera A, Verhoest NEC, Tilahun SA, Alamirew T, Adgo E, Moges MM, Nyssen J (2019) Performance of small-scale irrigation schemes

- in Lake Tana Basin of Ethiopia: technical and socio-political attributes. *Phys Geogr* 40(3):227–251
2. Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration-guidelines for computing crop water requirements-FAO irrigation and drainage paper 56. Fao, Rome 300(9):D05109
  3. Awulachew SB, Erkossa T, Namara RE (2010) Irrigation potential in Ethiopia—constraints and opportunities for enhancing the system, International Water Management Institute. Colombo, Sri Lanka
  4. Awulachew, Seleshi B, Merrey, Douglas J (2007) Assessment of small-scale irrigation and water harvesting in Ethiopian agricultural development. International Water Management Institute (IWMI)
  5. Awulachew SB, Erkossa T, Namara, RE (2010) Irrigation potential in Ethiopia. Constraints and opportunities for enhancing the system; International Water Management Institute: Addis Ababa, Ethiopia
  6. Blake GR (1965) Bulk density. Methods of soil analysis: part 1 physical and mineralogical properties, including statistics of measurement and sampling, 9, 374–390
  7. Bos MG (1997) Performance indicators for irrigation and drainage. *Irrig Drain Syst* 11(2):119–137
  8. Bouyoucos GJ (1951) A recalibration of the hydrometer method for making mechanical analysis of soils 1. *Agron J* 43(9):434–438
  9. Cakmak B (2003). Evaluation of irrigation system performance with comparative indicators in irrigation schemes, Kizilirmak Basin, Turkey. *Pakistan Journal of Biological Sciences (Pakistan)*
  10. Change, Ethiopian Panelon Climate (2015) First assessment report working group ii-climate change impact, vulnerability, adaptation and mitigation V: Ethiopian AcademyofSciences.
  11. Chazovachii B (2012) The impact of small-scale irrigation schemes on rural livelihoods: the case of Panganai irrigation scheme Bikita District Zimbabwe. *Journal of Sustainable Development in Africa* 14(4):217–231
  12. Degirmenci H, Büyükcangaz H, Kuscü H (2003) Assessment of irrigation schemes with comparative indicators in the Southeastern Anatolia Project. *Turk J Agric For* 27(5):293–303
  13. Döll P (2002) Impact of climate change and variability on irrigation requirements: a global perspective. *Clim Change* 54(3):269–293
  14. Doorenbos J, Kassam AH (1979) Yield response to water. FAO Irrigation and drainage paper 33:193
  15. FAO (Food and Agriculture Organization) (1989) Guideline for designing and evaluating surface irrigation systems. Irrigation and drainage paper. No. 45.FAO, Rome
  16. FAO(Food and Agriculture Organization) (1992) Ninth meeting of the east and southern African sub-committee for soil correlation and land evaluation. Soil bulletin
  17. FAO(Food and Agriculture Organization) (1998) Crop evapotranspiration-guidelines for computing crop water requirements. FAO irrigation and drainage paper, 56, Rome
  18. Feyen J, Zerihun D (1999) Assessment of the performance of border and furrow irrigation systems and the relationship between performance indicators and system variables. *Agric Water Manag* 40(2–3):353–362
  19. Hillel D (1997) Small-scale irrigation for arid zones: principles and options: Food & Agriculture Org
  20. Ingle PM, Shinde SE, Mane MS, Thokal RT, BL, Ayare. (2015) Performance evaluation of a minor irrigation scheme. *Research Journal of Recent Sciences ISSN 2277:2502*
  21. IWMI(international water management institute) (2010) Irrigation potential in Ethiopia constraints and opportunities for enhancing the system
  22. Kamwamba-Mtethiwa J, Weatherhead K, Knox J (2016) Assessing performance of small-scale pumped irrigation systems in sub-Saharan Africa: evidence from a systematic review. *Irrig Drain* 65(3):308–318
  23. Kassa T (2017) Comparative performance analysis of two small-scale irrigation schemes: case of Tahtay Tsalit and Mychew, Tigray, Ethiopia. (Master of Science), Arba Minch University
  24. Lambisso R (2008) Assessment of design practices and performance of small-scale irrigation structures in the south region
  25. Liu G, Hanlon E (2012) Soil pH range for optimum commercial vegetable production
  26. Michael AM (2008) Irrigation theory and practice, 2nd edn. VIKAS Publishing house Pvt Ltd., India
  27. Miller WR, Donahue RL (1995) Soils in our environment, 7th edn. Prentice Hall Inc, New Jersey, p 649p
  28. MoAFS (2002) Assessment of irrigation efficiency in traditional smallholder schemes in Pangani and Rufji basins
  29. Moges F (2019) Performance evaluation of gold small-scale irrigation scheme in Assosa Woreda, Benishangul Gumuz Regional State. Hawassa University, Ethiopia
  30. Molden DJ, Sakthivadivel R, Perry CJ, De Fraiture C (1998) Indicators for comparing the performance of irrigated agricultural systems (Vol. 20): IWMI
  31. Olabisi A, Joshua AT, Benjamin O (2017) Experimental determination of the effect of notch shape on weir flow characteristics using constant head discharge apparatus. *Asian Journal of Current Research* 2(2):55–64
  32. Oni SA, Maliwichi LL, Obadire OS (2011) Assessing the contribution of smallholder irrigation to household food security, in comparison to dryland farming in Vhembe district of Limpopo province, South Africa. *Afr J Agric Res* 6(10):2188–2197
  33. Pereira LS (1999) Higher performance through combined improvements in irrigation methods and scheduling: a discussion. *Agric Water Manag* 40(2–3):153–169
  34. Raghuvanshi NS, Wallender WW (1998) Optimal furrow irrigation scheduling under heterogeneous conditions. *Agric Syst* 58(1):39–55
  35. Renault D, Facon T, Wahaj R (2007) Modernizing irrigation management: the MasscotE approach—mapping system and services for canal operation techniques (Vol. 63): Food & Agriculture Org
  36. Savva AP, Frenken K (2002) Irrigation manual. Planning, development monitoring and evaluation of irrigated agriculture with farmer participation. FAO
  37. Seleshi B, Mekonen A (2011) Performance of irrigation: an assessment at different scales in Ethiopia. *Exp Agric* 47(S1):57–69
  38. Şener M, Yüksel AN, Konukcu F (2007) Evaluation of Hayrabolu irrigation scheme in Turkey using comparative performance indicators
  39. Shen J (1981) Discharge characteristics of triangular-notch thin-plate weirs: studies of flow to water over weirs and dams: US Geological Survey: for sale by Supt. of Docs., USGPO
  40. Shenkut A (2015) Performance assessment irrigation schemes according to comparative indicators: a case study of Shina-Hamusit and Selamko, Ethiopia. *Int J Sci Res Publ* 2:451–465
  41. Shiberu E, Hailu HK, Kibret K (2019) Comparative evaluation of small scale irrigation schemes at Adami Tulu Jido Kombolcha Woreda, Central Rift Valley of Ethiopia. *Irrigation & Drainage Systems Engineering*, 5. <https://doi.org/10.4172/2168-9768.1000226>
  42. Tesfaye H, Danato M, Woldemichael A (2019) Comparative performance evaluation of irrigation schemes in southern Ethiopia. *Irrigation & Drainage Systems Engineering*
  43. Wondatir, Solomon. (2016). Performance evaluation of irrigation schemes. Arba Minch University
  44. You L, Ringler C, Wood-Sichra U, Robertson R, Wood S, Zhu T, ... Sun Y (2011) What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. *Food Policy* 36(6): 770-782

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.