



Performance Evaluation of Small-Scale Irrigation Scheme: A Case Study of Temsa Small Scale Irrigation Scheme of Goma District, Jimma Zone, South West Ethiopia

Authors: Tilahun, Etefa, Tadesse, Minda, Tadesse, Hewan, and Asefa, Addisu

Source: Air, Soil and Water Research, 18(1)

Published By: SAGE Publishing

URL: <https://doi.org/10.1177/11786221241310368>

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Performance Evaluation of Small-Scale Irrigation Scheme: A Case Study of Temsa Small Scale Irrigation Scheme of Goma District, Jimma Zone, South West Ethiopia

Air, Soil and Water Research
Volume 18: 1–19
© The Author(s) 2025
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/11786221241310368



Etefa Tilahun , Minda Tadesse , Hewan Tadesse and Addisu Asefa

Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, Ethiopia.

ABSTRACT: A study was carried out from November to May in the cropping season of 2016E.C to evaluate the performance of Temsa small scale irrigation scheme. Both internal and external indicators were considered for evaluation. The internal indicator efficiencies such as conveyance, application, storage, distribution uniformity, and deep percolation ratio and the external indicators such as agricultural output, water supply, water delivery capacity, physical, and economic and financial indicators were evaluated. The result reveals that, the average conveyance efficiency of the main, secondary, and tertiary canals were 79.6%, 85.6%, and 84.7%, respectively. The scheme has on average application efficiency (Ea), storage efficiency, deep percolation ratio, and distribution uniformity of 40.87%, 78.04%, 59.70%, and 93.33%, respectively. The poor Ea and low conveyance efficiency of the canal affected the overall scheme performance. The result reveals that, the overall efficiency of the scheme was 23.19%. The four basic agricultural output indicators of the scheme such as output per unit irrigated area, output per unit command area, output per unit irrigation diverted, and output per unit water consumed were 4,738.58 US\$/ha, 1,176.08 US\$/ha, 1.16 US\$/m³, and 0.89 US\$/m³, respectively. This shows that, the command area was beneficial and was giving a revenue for the farmers at the cropping season. The relative irrigation supply and the water delivery capacity of the canal were 2.37 m³ and 83%, respectively. In the current study, the irrigation ratio and the sustainability of the irrigated area were 0.25 and 0.43, respectively. The irrigation ratio was low due to the designing problem. Availability of water throughout the year and market accessibility near the scheme were the advantage of the scheme that encourage the farmers. However, the input costs were affecting the return obtained from the product. Hence it is better to provide access to credit for the sustainable production and improve the farmers income.

KEYWORDS: Temsa scheme, efficiency, external indicators, irrigation scheme, internal indicators, performance evaluation

RECEIVED: September 19, 2024. **ACCEPTED:** December 12, 2024.

TYPE: Research Article

CORRESPONDING AUTHOR: Etefa Tilahun, Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, P. O. Box 192, Jimma 198, Ethiopia. Email: etefatilahun@gmail.com

Introduction

Ethiopia, the second most populous country in Africa (Worldometer, 2023), would not be able to achieve its food security needs with a rainfed farming system due to land degradation, soil fertility depletion, climate change effects, and regional and temporal rainfall variability. Land degradation, soil fertility deterioration, rainfall variability in space and time, and soil moisture stress all had a significant impact on production (Worqlul et al., 2019; Zerssa et al., 2021). Since rainfall patterns in many countries have grown more unpredictable and inconsistent with conventional farming seasons, many development partners have recognized irrigation as the solution to the food insecurity problem that many developing countries face (Bowen et al., 2023). As a result, Ethiopia is concentrating on irrigated agriculture by building dams and other water harvesting structures as well as irrigation infrastructure in small- and large-scale irrigation schemes for increased productivity and sustainable production. Therefore, the government is funding the creation of small-scale irrigation projects based in communities in an effort to control food insecurity (Ministry of Water Resources, 2001).

Small-scale irrigation is irrigated agriculture production on a small plot of land, and the construction, operation, and maintenance require a relatively lower investment cost and is considered

important for food security and food self-sufficiency. Its development has a significant role in raising production and productivity to achieve food self-sufficiency and ensure food security at the household and national levels (Brabben et al., 2004; Gebregziabher et al., 2009; Tesfaye et al., 2008). It is a means of alleviating poverty and can also stabilize agricultural output, improve livelihood circumstances in communities, and lessen the negative impacts of erratic rainfall. Typically, irrigation from the small-scale plan might lead to food self-sufficiency, advanced economic income, and assets accumulation (Bekele, 2011). It is also possible to raise productivity per area, increase the amount of production produced annually, and solve the issue of unpredictable rainfall, all of which could result in more sustainable and better incomes for better livelihoods (Smith, 2004).

Even though the focus of irrigation development in Ethiopia is to maximize agricultural production, to satisfy the country's ever-increasing food demand, and to improve the income of small-holder farmers through the construction of schemes, the performance of most schemes was below the expected design (Embaye et al., 2020; Haile et al., 2020). Ethiopia's irrigation schemes performed poorly due to a combination of institutional, social, technical, and environmental problems (Amede, 2015; Awulachew & Ayana, 2011; Berhane et al., 2016). According to Mengiste and Kidane (2016), insufficient beneficiary participation



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

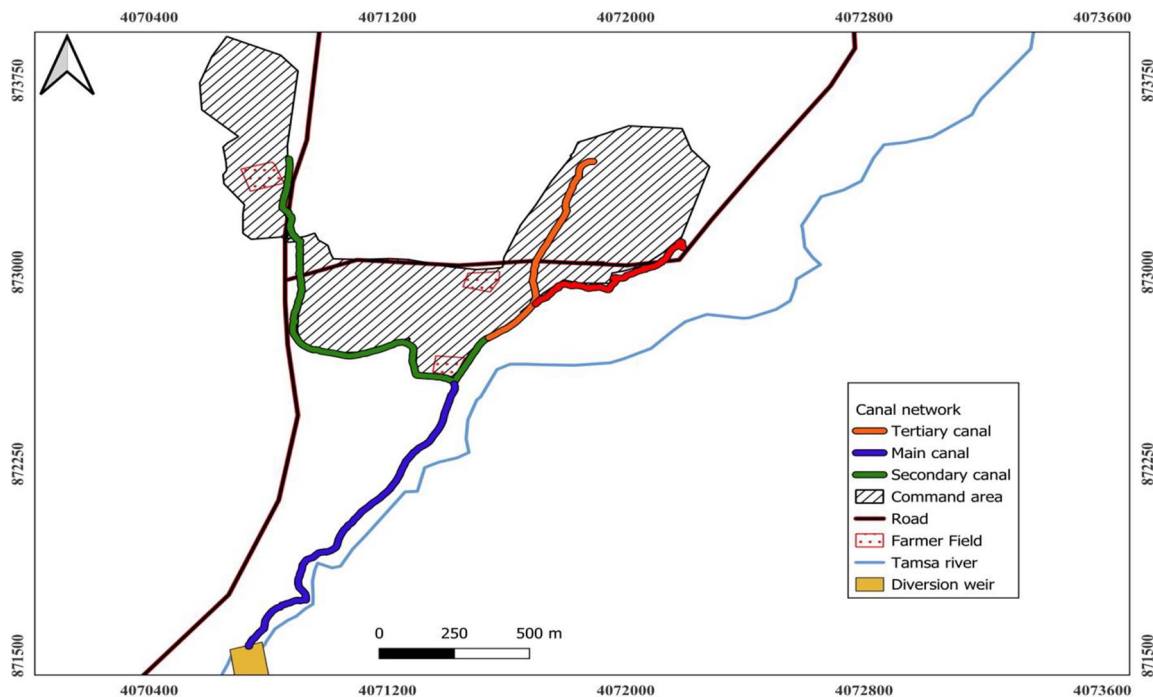


Figure 1. Geographical location of the study area.

and unstable land ownership have been the primary causes of irrigation projects failure. Even though these studies were widely shown, some of the opportunities that might indicate performance improvements were the efficient administration of the plan and the management of irrigation water at the field. There has been a growing push to enhance irrigation schemes' performance in order to guarantee land and water production because of farmers' growing interest in irrigation, rising water demand, and the highly committed support of extension experts.

Researchers and irrigation scheme administrators are increasingly evaluating the performance of irrigation schemes due to their significant impact on scheme productivity (Fufa, 2017). These kinds of practices could aid in the development of potential intervention mechanisms that could be implemented to enhance the schemes' performance. The intended purpose of the designed scheme must be determined by regularly evaluating and monitoring the irrigation system with respect to crop output, land, and water productivity as the irrigation system's ultimate goals (Abo et al., 2024; Moges, 2022). Therefore, the overall objective of the current study was to evaluate the performance of Tamsa small scale irrigation scheme in the cropping season of 2016 E.C. The specific objectives were (1) To evaluate the internal indicators of the small-scale irrigation scheme. (2) To evaluate the external indicators of small-scale evaluation at Tamsa scheme.

Materials and Methods

Description of the study site

The study site was located in Jimma zone of the Oromia regional state in Gomma district at a place called "Dalacho"

approximately 55 km from Jimma town. Geographically it is situated between 7°86.24' latitude, 36°6.5' longitude, and at an altitude of 1,642 m above mean sea level (AMSL; Figure 1). It has a long year maximum and minimum temperature, average relative humidity, average wind speed and average solar radiation of 31.4°C, 9.9°C, 73.4%, 1.8 m/s, and 6.1 hr, respectively. The total annual average rainfall was 1,655 mm distributed non-uniformly mainly in the summer season (Figure 2).

Materials used to conduct the study

Important materials for conducting the study were global positioning system (GPS) to collect the current irrigated area and command area of the scheme; auger to collect the soil sample; current meter to measure water flow in the irrigation canal; tape meter to measure the dimensions of the structures (depth and width of the canal); Parshall flume to measure the applied water in the irrigation field; stop watch to measure the time it took for applying water to the field; pressure plate was used to determine the available soil water content at field capacity (FC) and permanent wilting point (PWP) and oven was used for drying the soil in the laboratory for determining the moisture content of the soil.

Methods of data collection

Data collection. Direct measurements, field observation, farmers response, Gomma District, and Jimma Zone Agriculture office expert interviews were collected. Primary data such as flow data, current irrigated area, crop type on the field, soil data, functional and non-functional structures, and the cross-section

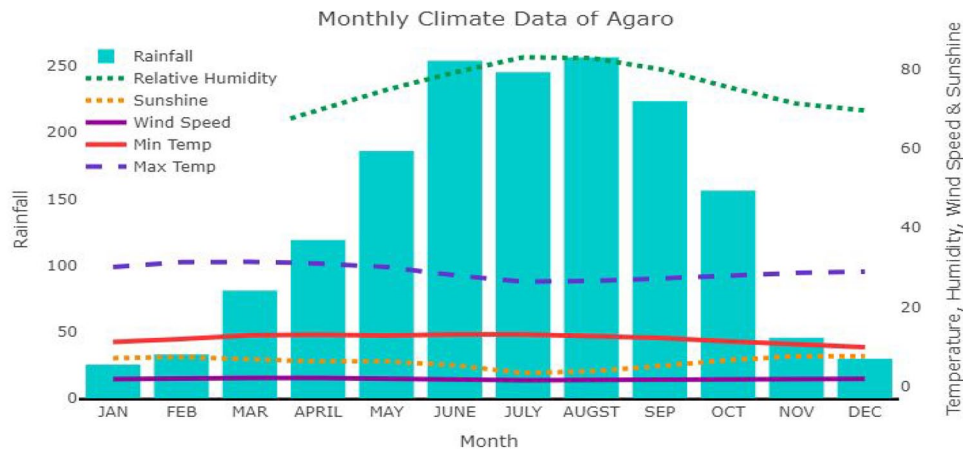


Figure 2. Climatic condition of the study site.

of the irrigation structure were collected through direct measurement, laboratory and fieldwork, field observation, stakeholder interviews, and questionnaires. Secondary data such as meteorological data, crop property data which are input for the CROPWAT software such as root length of the crop, depletion of the crop, crop coefficient, and crop patterns (Allen et al., 2016; Luo et al., 2022), were collected from National Meteorological Service Agency (NMSA) and relevant documents, studies, and other useful written materials. The command area and maintenance cost were collected from the design documents and interviewing the Agricultural Office experts.

Soil data. Soil samples were collected at the head, middle, and tail reaches of the scheme up to 90 cm at 30 cm intervals using auger. According to Tesfahunegn (2014), a method of soil sampling was random composite soil sampling techniques. Soil texture was estimated using a hydrometer test after drying in an oven at 105°C for 24 hr, and field capacity and permanent wilting point were evaluated by using a pressure plate apparatus. A 5-cm × 5-cm core sampler was utilized to extract soil samples from the head, middle, and tail reaches from five points each at three different depths also, to assess the soil's bulk density. The bulk density of soil (ρ_b) at each soil depth was estimated as suggested by Al-Shammary et al. (2018). The soil samples collected from the three areas at different depths before and after irrigation were weighed and oven dried to determine the soil water content in the soil and other efficiencies.

Methods of determining crop water and irrigation water requirement of the crop

Delivering the intended quantity of water for the crops in the scheme after construction is the ultimate goal of small-scale irrigation schemes. Therefore, the CROPWAT 8.0 computer program was used to estimate the total water requirements of the crops grown in the irrigation schemes. The reference evapotranspiration (ET_0) was calculated using the Food and

Agricultural Organization (FAO, 1992) Penman-Monteith strategy, each crop's K_c value was taken from FAO documents FAO (1992) and FAO (1998), and the USDA soil preservation strategy was used to determine the effective rainfall (P_{eff}).

$$ET_c = K_c \times ET_0 \quad (1)$$

Where; K_c = Crop Coefficients

P_{eff} = Effective Rainfall

ET_0 = Reference crop evaporation

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

Where: ET_0 is the reference evapotranspiration (mm/day), Δ is the slope of the saturation vapor pressure curve (kPa/°C), R_n is net radiation at the crop surface (MJ/m² day), G is the soil heat flux density (MJ/m² day), T is the mean daily air temperature at 2 m height (°C), U_2 is the wind speed at 2 m height (m/s), $e_s - e_a$ is saturation vapor pressure deficit (kPa), e_s is the saturation vapor pressure at a given period (kPa), e_a is actual vapor pressure (kPa), and γ is the psychrometric constant (kPa/°C).

$$IWR = ET_c - P_{eff} \quad (3)$$

Evaluation of the internal indicators

Flow measurement and conveyance efficiency (E_c). To determine the conveyance efficiency of the canal, a current meter (electronic current meter) device was used at the head, middle, and tail reach of the canal. It is a widely used device for the measurement of flow velocity and, hence, the discharge in an open channel flow was determined. It consists of a small wheel with cups at the periphery or propeller blades rotated by the force of the flowing water, and a tail or fins to keep the instrument aligned in the direction of flow. The cup-type current meter has a vertical axis, and is a more rugged instrument, which can

be handled by relatively unskilled technicians. Currently the cup type current meter was used to determine the conveyance efficiency of the canal.

To measure the conveyance efficiency, a regular cross-section of the canal was used and the cross-sectional area of the canal, that is, the depth and width of the canal was measured by a tape meter. The flow velocity was measured by the current meter. The water flow discharge was the product of cross-sectional area and the flow velocity. For the measurement a straight canal section and steady flow was considered. This procedure was used at the middle and tail of the scheme similarly. Since there was no secondary and tertiary canal, it was not measured. Finally, the canal conveyance efficiency was determined by considering the flow at two points, the first flow section was the inflow and the other section was the out flow and it is calculated using Equation 4 (Michael, 2008).

$$Q = AV \quad (4)$$

Where Q = Discharge (m^3/s),
 A = Cross-sectional area (m^2), and
 V = Flow velocity (m/s)

$$EC = \frac{Q_{out}}{Q_{in}} \times 100 \quad (5)$$

Where Q_{out} = Out flow discharge (m^3/s) Q_{in} = Inflow discharge (m^3/s)

The losses in the conveyance system was computed as;

$$L_c = L_{in} - L_{out} \quad (6)$$

Where L_c = Conveyance loss (m^3/s)

Application efficiency (E_a). Soil samples were collected from the three sites of the scheme namely from the top, middle, and tail of the scheme from the selected farmers to determine the soil physical and chemical properties such as soil moisture, texture, soil field capacity and permanent wilting point. It was collected based on the root depth of the selected test crop (tomato at the head, wheat at the middle, and tail reach) for assessment before and after irrigation. From each site of the scheme composite soil samples were collected from five representative points, two sample from the first one-third, and the last one-third and one from the second one-third area of the farm at three depths at an interval of 30 cm from 0 up to 90 cm using soil auger. The bulk density, the soil water content, and the total available water content which were the basic to determine the application efficiency were determined by using the following equation (Equations 7–9).

$$BD = \frac{W_s}{V_c} \quad (7)$$

$$TAW = 1,000 \sum (\theta_{FC} - \theta_{PWP}) \times R_d \quad (8)$$

$$\theta_v = \theta_m \times BD \quad (9)$$

Where: BD = is soil bulk-density (g/cm^3), W_s = is mass of dry soil (g), V_c = is volume of soil in the core (cm^3), TAW = is volumetric total available water in the root zone (mm/m), R_d = root depth (m), θ_{FC} = volumetric moisture content at field capacity (m^3/m^3), θ_v = volumetric moisture content in (%), and θ_{PWP} = volumetric moisture content at permanent wilting point (m^3/m^3).

The application efficiency (E_a) was determined by measuring the depth of water applied to each field on each specific irrigation field to the selected crop. Before irrigation, soil sample was collected and after that irrigation was given to the crop and, 2 days after irrigation, the depth of water stored in the root zone was determined as the difference between the before and after irrigation moisture contents of the soil. To do this a total of 30 soil samples, 15 samples before and 15 samples after irrigation were collected at a 30 cm depth interval up to 90 cm from the top, middle, and tail reach, respectively. The application efficiency was determined by using Equation 10.

$$E_a = \frac{\text{Average depth of water stored in the root zone of the plant } (W_s)}{\text{Average water delivered to the field } (W_f)} \times 100 \quad (10)$$

$$W_s = \frac{\theta_v \times d}{100} \quad (11)$$

$$W_f = \frac{Q \times t}{A} \quad (12)$$

Where Q = Discharge of irrigation water applied to the field (L/s), A = Irrigated land area with in the applied time (m^2), t = application time (s), and d = depth of soil (mm).

Storage efficiency (E_s). To determine the water stored in the soil root zone of each field, soil samples were collected from three representative sites of the selected farm at the top, middle, and tail reach. Similarly, five samples were collected, two sample from the first one-third and the last one-third and one from the second one-third area of the farm at a depth of 0 to 30, 30 to 60, and 60 to 90 cm depth based on the root depth of the crop before and after each irrigation event. The moisture content was determined using the gravimetric method.

The storage efficiency is the ratio of the quantity of water stored in the root zone to quantity water needed in the root zone of the crop. It was calculated by using Equation 13.

$$E_s = \frac{W_s}{W_n} \times 100 \quad (13)$$

Where E_s = Storage efficiency (%); W_s = water stored in the root zone during irrigation (mm); and W_n = Water needed in the root zone prior to irrigation.

The water needed in the root zone prior to irrigation was computed using Equation 14 (Michael, 2008).

$$W_n = \sum_{i=1}^n \left(\frac{Mfci - Mbi}{100} \right) \times \frac{\rho_b}{\rho_w} \times di \quad (14)$$

Where: W_n = net amount of water to be applied during an irrigation (mm), $Mfci$ and Mbi = moisture content at field capacity and before irrigation in the i th layer of the soil (%), ρ_b = bulk density of the soil in the i th layer and density of water (g/cm^3), di = depth of the soil layer within the root zone (mm), and n = number of soil layers in the root zone.

Water distribution uniformity (DU). To determine the water stored in the soil root zone, each field was divided into three parts at the head, middle, and tail reach of the field. Totally, from five places at a depth of the 0 to 30, 30 to 60, and 60 to 90 cm soil sample was collected before and after each irrigation event. The distribution uniformity of the water applied to the field was determined by using Equation 21. After soil moisture contents of the soil samples was determined gravimetrically, at the selected points, the depth of stored water at particular soil layer (X (0–30), X (30–60), and X (60–90)) was calculated using Equation 15:

$$X = \left(\frac{Mai - Mbi}{100} \right) \times \frac{\rho_b}{\rho_w} \times di \quad (15)$$

Where: X = soil moisture content stored at a respective depth interval (mm), Mai and Mbi = moisture content of the i th layer of the soil after and before irrigation, respectively on weight basis (%), ρ_b and ρ_w = Bulk density of the soil in the i th layer and density of water (g/cm^3), and di = depth of the soil in the i th layer (mm). The total depth of water stored at each point (X1–X5) was determined, by summing up the values of X1(0–30), X1(30–60), and X1(60–90) of that specific point, that is,

$$X_1 = X_{1(0-30)} + X_{1(30-60)} + X_{1(60-90)} \quad (16)$$

$$X_2 = X_{2(0-30)} + X_{2(30-60)} + X_{2(60-90)} \quad (17)$$

$$X_3 = X_{3(0-30)} + X_{3(30-60)} + X_{3(60-90)} \quad (18)$$

$$X_4 = X_{4(0-30)} + X_{4(30-60)} + X_{4(60-90)} \quad (19)$$

$$X_5 = X_{5(0-30)} + X_{5(30-60)} + X_{5(60-90)} \quad (20)$$

Finally, the distribution uniformity was determined by

$$DU = \frac{\bar{X}_{Lq}}{\bar{X}_m} \times 100 \quad (21)$$

Where: Du = water distribution uniformity (%), \bar{X}_{Lq} = the mean of lower quarter depth of water infiltrated (mm), and \bar{X}_m = the mean depth of all water infiltrated (caught; mm).

Deep percolation ratio (DPR). During the application of the intended amount of water at the field, the water could be delivered in excess, it could be due to the technical problem and in this case, it may cause a loss of water and a run off and could be stored as a deep percolation. This could affect the performance of the scheme. It was calculated using Equation 22 below (Abo et al., 2024; Feyen & Zerihun, 1999; Markos et al., 2019).

$$DPR = 100 - Ea - RR \quad (22)$$

Where: DPR = Deep percolation ratio (%), Ea = application efficiency (%), and RR = runoff ratio (%).

However, since when the farmers irrigate the field, they use a tied furrow and due to this there was no runoff loss. Finally, the overall scheme efficiency was calculated as the product of conveyance and application efficiency FAO (2002):

$$E_p = E_c \times E_a \quad (23)$$

Where; E_p = overall scheme efficiency (%), E_c = conveyance efficiency (%), and E_a = application efficiency (%)

Determination of the external performance indicators

To determine the performance of the scheme Nine external indicators were used as illustrated by International Water Management Institute (Molden et al., 1998).

Agricultural output indicators. The yield during the cropping season, the market price that farmers earned, and other input costs for seed, fertilizer, pesticide, and labor were used to calculate agricultural output indicators like output per irrigated area, output per unit command area, output per irrigation water diverted, and output per unit water consumed. Using the global positioning system (GPS), the command area the irrigable cropped area was gathered from the field. The amount of diverted water at intake of the schemes were also measured at the field by Parshall flume. The following equations were used to compute the four basic agricultural output indicators (Molden et al., 1998).

$$\begin{aligned} \text{Output per unit irrigated area } \left(\frac{\$}{\text{ha}} \right) \\ = \frac{\text{Production}}{\text{Irrigated cropped area}} \end{aligned} \quad (24)$$

$$\begin{aligned} \text{Output per unit command area } \left(\frac{\$}{\text{ha}}\right) \\ = \frac{\text{Production}}{\text{Command area}} \end{aligned} \quad (25)$$

$$\begin{aligned} \text{Output per unit irrigation diverted } \left(\frac{\$}{\text{m}^3}\right) \\ = \frac{\text{Production}}{\text{Irrigation diverted}} \end{aligned} \quad (26)$$

$$\begin{aligned} \text{Output per unit water consumed } \left(\frac{\$}{\text{m}^3}\right) \\ = \frac{\text{Production}}{\text{Volume of water consumed by ET}} \end{aligned} \quad (27)$$

Water supply indicators. After supplying the crop water demand for the crop during the growth season, the water supply performance indicators such as relative irrigation and water supply were evaluated. Irrigation supply is the volume of irrigation water delivered from the water source, measured at the head-works of the schemes. Relative water supply is the sum of delivered irrigation water and effective rainfall. The crop water requirement was calculated for each month using the following equation for the crop currently available on the field.

$$\begin{aligned} CWR_{\text{monthly}} = CWR_{\text{Wheat}} + CWR_{\text{Tomato}} + CWR_{\text{Cabbage}} \\ + CWR_{\text{Onion}} + CWR_{\text{Water Melon}} \\ + CWR_{\text{Hot pepper}} + CWR_{\text{Carrot}} \\ + CWR_{\text{Kchat}} + CWR_{\text{Green Lettuce}} \end{aligned} \quad (28)$$

$$IWD = CWR(m^3) - P_{\text{eff}}(m^3) \quad (29)$$

$$IWS = DIW(m^3) + P_{\text{eff}}(m^3) \quad (30)$$

After determining the crop water requirement, effective rainfall, irrigation water demand, and water supply both the relative water supply and irrigation supply were determined using Equations 31 and 32 as shown below.

$$RIS = \frac{IWS(m^3)}{IWD(m^3)} \quad (31)$$

$$RWS = \left(\frac{IWS(m^3)}{CWR(m^3)}\right) \quad (32)$$

Where: RWS=Relative water supply (m^3), IWS=Irrigation water supply (m^3), IWD=Irrigation water demand (m^3), CWR=Crop water requirement (m^3).

Water delivery capacity indicator (WDC). The water delivery capacity was determined from the measurement taken from the off taking canal using the canal cross sectional area, flow

velocity in the canal and free board of the constructed structure. The maximum (peak) monthly crop water demand was computed by CROPWAT 8.0 and calculated by Bos et al. (1994) as shown below in Equation 33.

$$WDC = \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}} \quad (33)$$

Physical indicators. Physical performance indicators were evaluated based on the irrigation ratio and sustainability of irrigated area as discussed by Molden et al. (1998). Both the irrigation ratio (IR) and sustainability of the irrigated area (SIA) were used to evaluate the physical indicators.

- 1. Irrigation Ratio (IR):** It indicates the degree of utilization of the available irrigable area at a particular time. Irrigation ratio was determined by the ratio of currently irrigated area to the command area (Bos et al., 1994).

$$IR = \frac{\text{Irrigated cropped area}}{\text{Command Area}} \quad (34)$$

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

- 2. Sustainability of Irrigated Area (SIA):** was evaluated by collecting and delineating the area under irrigation and its potential obtained from the Gomma district irrigation scheme office. It was computed by using the following Equation 35 (Molden et al., 1998).

$$SIA = \frac{\text{Currently Irrigable Area}}{\text{Initially Irrigated Area}} \quad (35)$$

Where: Current irrigable area is the area currently irrigated (ha), and initially irrigated area is the designed irrigable area (ha).

Economic and financial indicators

Even though the constructed scheme could be advantageous in granting the farmers possibility to produce in a dry period and sustainable production, it has to be evaluated economically and financially. To do this both the gross return on investment, the financial self-sufficiency and profitability in terms of area-based profitability per unit area and per unit water used were evaluated.

Gross return on investment. To evaluate the gross return on investment, an assessment was made of how cost over runs are financed and costs under-runs deployed. In the scheme the

main indicators for the financial evaluations were input costs such as seed, fertilizer, and chemical cost for herbicides, and costs for hiring the security guard. The gross return on investment was evaluated in Equation 36.

$$\begin{aligned} & \text{Gross return on investment} \\ & = \frac{SGVP}{\text{Cost of irrigation infrastructure}} \end{aligned} \quad (36)$$

$$\begin{aligned} SGVP_{Crop} & = \text{Yield of crop}_1 \\ & \times \frac{\text{Price of crop}_1}{\text{Price of base crop}} \times \text{Area of crop}_1 \end{aligned} \quad (37)$$

Where: SGVP = Standard Gross Value of Production

Financial self-sufficiency. It was evaluated by considering the revenue they get from the field and the expected construction material cost required for maintenance and the cost required for labor force and masonry expert.

$$\begin{aligned} & \text{Financial self – sufficiency} \\ & = \frac{\text{Revenue from Irrigation}}{\text{Total Operation and Maintenance expenditure}} \end{aligned} \quad (38)$$

Where: Revenue from irrigation, is the revenue generated from fees, total operation (O), and maintenance (M) expenditures are the amount expended locally through O&M plus outside subsidies from the government.

Profitability. Both the profitability of the area used and water applied per hectare of land were evaluated to assess the profitability of the scheme to determine the profitability of the scheme, to enhance the production and productivity.

$$\begin{aligned} & \text{Area-based profitability} \\ & = \frac{\text{Incremental benefit per unit area}}{\text{Total irrigation expenses}} \end{aligned} \quad (39)$$

$$\begin{aligned} & \text{Area-based profitability} \\ & = \frac{\text{Incremental benefit per unit water}}{\text{Total irrigation expenses}} \end{aligned} \quad (40)$$

Results and Discussion

Soil physicochemical properties

One of the factors that affect the performance of irrigation scheme and the effectiveness of irrigation management is the soils textural classification since it affects the soil water holding capacity and also the irrigation scheduling. The soil physico-chemical data reveals that the dominant textural class of the soil were sandy clay loam (SCL; Table 1). Similarly, research results

conducted by Dessalew and Dar (2016) showed that the soil textural classes critically affect water-holding capacity and further irrigation scheduling. The average total available water (TAW) of the soil in the current finding was in the range of 117 up to 146 mm/m (Table 1). The soil texture at each horizon and the water that was released from the headwork could be the factor for the variation of the total available water in each part of the scheme. According to the finding of Agmasie et al. (2022), the degree of variability of total available water (TAW) could be attributed to variability in their soil textural classes. The TAW soil water obtained in the current finding is categorized under good soil moisture condition as suggested by Kassa and Ayana (2017).

It has an average bulk density of 1.17 up to 1.38 g/cm³. A bulk density between 1.1 and 1.9 g/cm³ were normal and recommended for most irrigable soil (Greaves, 2007). Similarly, the result of this study revealed that, the bulk density was in the recommended range implying that there would be no extreme effect of the recorded bulk density on the water availability for plants. Dananto and Alemu (2014), justified that soils having moderate moisture-holding capacity are better for high irrigation performance. In this study, the gravimetric water content also indicated average condition, implying the condition of the soil was good at holding appropriate moisture for crop development.

Water and irrigation requirement of the crop in the scheme

To evaluate both the internal and external performance of the scheme, determining the water requirement and irrigation water supplied to meet the water demand was the basic. In the cropping season of 2016 E.C, the cultivated crops on the scheme were wheat, tomato, cabbage, potato, water melon, hot paper, carrot, kchat, and green lettuce. The water requirement of each crop determined by the crop wat 8.0 in the cropping season were 382 mm for wheat, 556 mm for tomato, 549 mm for cabbage, 485 mm for onion, 399 mm for water melon, 360 mm for hot pepper, 279 mm for carrot, 588 mm for kchat, and 279 mm for green lettuce. In the cropping season the net irrigation requirements were 275 mm for wheat, 396 mm for tomato, 386 mm for cabbage, 360 mm for onion, 292 mm for water melon, 225 mm for hot pepper, 187 mm for carrot, 229 mm for kchat, and 182 mm for green lettuce (Table 2). Similarly, Dirirsa et al. (2017) and Abebe and Kebede (2020) obtained approximately similar water requirement for tomato. Amdneh and Gebul (2023) obtained similar CWR for wheat. Beshir (2017) obtained for cabbage. Tamene and Haile (2021) obtained CWR of onion in the same range. Enyew et al. (2020) suggested the same range of CWR of water melon. Wale and Girmay (2019) and Gelu et al. (2024) obtained CWR of hot pepper in the same range. Ashine et al. (2024) obtained CWR of carrot in the same range. Atroosh and Al-Moayad (2012) suggested CWR of Kchat similar to the current finding and Acar (2020) suggested a similar CWR of green lettuce.

Table 1. Physicochemical Properties of Soil of The Study Site.

NO	TESTED PARAMETER	SOIL DEPTH (CM)			AVERAGE
		0–30	30–60	60–90	
At the head of the scheme					
1	Sand (%)	55	65	41	53.7
2	Clay (%)	29	25	41	31.7
3	Silt (%)	16	10	18	14.6
4	Soil textural Class	SCL	SL	CL	SCL
5	PH	5.02	5.06	5.27	5.12
6	Total Nitrogen (TN)	0.42	0.26	0.25	0
7	Organic Carbon (OC) (%)	2.18	1.74	1.60	1.84
8	Available P (ppm)	3.85	4.01	3.36	4
9	Soil bulk density (g/cm ³)	1.3	1.4	1.45	1.38
10	Field Capacity (FC) (%)	23.7	26.1	29.6	28.8
11	Permanent wilting point (PWP) (%)	15.5	17.8	20.0	18.2
12	Total available water (TAW) (mm/m)	106.6	116.2	139.2	146.28
At the middle of the scheme					
1	Sand (%)	53	61	66	60
2	Clay (%)	31	27	22	26.7
3	Silt (%)	16	12	12	13.3
4	Soil textural Class	SCL	SCL	SCL	SCL
5	PH	5.25	5.21	5.09	5.18
6	Total Nitrogen (TN)	0.37	0.29	0.36	0.34
7	Organic Carbon (OC) (%)	2.21	1.76	1.84	1.94
8	Available P (ppm)	3.44	2.78	2.95	3.05
9	Soil bulk density (g/cm ³)	1.29	1.52	1.17	1.32
10	Field capacity (FC) (%)	32.0	32.0	31.0	30.6
11	Permanent wilting point (PWP) (%)	21.0	21.0	19.9	20.5
12	Total available water (TAW) (mm/m)	141.9	167.2	129.87	133.32
At the tail reach of the scheme					
1	Sand (%)	55	71	45	57
2	Clay (%)	33	21	25	26.3
3	Silt (%)	12	8	30	16.7
4	Soil textural class	SCL	SCL	L	SCL
5	PH	5.61	5.08	5.11	5.27
6	Total Nitrogen (TN)	0.46	0.39	0.4	0.42
7	Organic Carbon (OC) (%)	1.97	1.82	1.88	1.89
8	Available P (ppm)	6.63	3.44	2.78	4
9	Soil bulk density (g/cm ³)	1.12	1.15	1.25	1.17
10	Field Capacity (FC) (%)	29.3	30.2	28.2	28.8
11	Permanent wilting point (PWP) (%)	18.8	18.7	16.5	18.8
12	Total available water (TAW) (mm/m)	117.6	132.25	146.25	117

Table 2. Crop Water (CWR) and Net Irrigation Requirement (NIR) of the Crop.

CROP	GROWTH PERIOD (MONTH)	KC	ETC (MM/DAY)	CWR (MM)	EFF RF (MM)	NIR (MM)	IRRIGATION WATER SUPPLIED (%)
Wheat	November	0.3	1.2	20	17	3	15
	December	0.6	2.4	76	28	48	63
	January	1.2	4.9	154	24	130	84
	February	0.9	4.4	125	31	94	75
	March	0.4	1.7	7	7	0	0
Total/cropping season				382	107	275	72
Tomato	November	0.6	2.5	64	34	34	54
	December	0.8	3.1	98	28	69	70
	January	1.1	4.8	150	24	124	82
	February	1.2	5.5	155	31	123	79
	March	1.0	4.7	89	42	45	50
Total/cropping season				556	160	396	71
Cabbage	November	0.7	2.9	75	34	41	54
	December	0.8	3.2	100	28	72	72
	January	1.0	4.3	133	24	109	82
	February	1.1	5.1	143	31	112	78
	March	1.0	5.0	96	44	52	54
Total/cropping season				549	161	386	70
Onion	November	0.7	2.9	76	34	42	55
	December	1.0	3.9	121	28	93	77
	January	1.1	4.5	140	24	116	83
	February	1.0	4.7	132	31	101	76
	March	0.8	3.88	16	8	8	50
Total/cropping season				485	125	360	74
Water melon	November	0.5	2.1	55	34	21	38
	December	0.9	3.6	114	28	86	75
	January	1.1	4.5	139	24	115	82
	February	0.9	4.0	91	21	70	77
Total/cropping season				399	107	292	73
Hot pepper	November	0.6	2.0	52	34	18	35
	December	0.7	2.4	74	28	46	62
	January	1.0	3.3	103	24	79	77
	February	1.0	3.6	101	31	70	69
	March	0.9	3.4	30	18	12	40

(continued)

Table 2. (continued)

CROP	GROWTH PERIOD (MONTH)	KC	ETC (MM/DAY)	CWR (MM)	EFF RF (MM)	NIR (MM)	IRRIGATION WATER SUPPLIED (%)
Total/cropping season				360	135	225	63
Carrot	November	0.7	2.35	61	34	27	44
	December	0.9	2.96	92	28	64	70
	January	1.0	3.32	103	24	79	77
	February	0.9	3.3	23	6	17	74
Total/cropping season				279	92	187	67
Kchat	November	0.4	1.2	30	34	0	0
	December	0.5	1.7	54	28	26	48
	January	1.0	3.4	105	24	81	77
	February	1.2	4.2	117	31	86	74
	March	1.2	4.3	135	70	65	48
	April	0.9	3.4	103	97	6	6
	May	0.7	2.4	44	75	0	0
Total/cropping season				588	359	229	39
Green lettuce	November	0.7	2.4	72	42	30	42
	December	1.0	3.1	95	28	67	71
	January	1.0	3.3	102	24	78	76
	February	1.0	3.3	10	3	7	70
Total/cropping season				279	97	182	65

In the cropping season, the total area of 8.92 ha of land was for wheat, 1.36 ha was for tomato, 0.76 ha was under cabbage, 0.51 ha was under onion, 0.09 ha was under water melon, 0.15 ha was under hot pepper, 0.61 ha was under carrot, 5.11 ha was under kchat, and 0.36 ha was under green lettuce. The amount of irrigation supplied for the crop in the cropping season in the scheme were 72% for wheat, 71% for tomato, 70% for cabbage, 50% for onion, 73% for water melon, 63% for hot pepper, 67% for carrot, 39% for kchat, and 65% for green lettuce. According to the finding on average the irrigation requirement could be above 60% based on the crop type, variety, and agroecology of the site. This study reveals that it needs supplementary up to full irrigation based on the crop type and specific planting date. Based on the area coverage of the crops, the net irrigation requirement of the crops was 50,803 m³.

Performance of the internal indicators

Conveyance efficiency (Ec). The conveyance efficiency of the main canal reveals that, at the head, middle, and tail reach of the scheme, the efficiency was 86.4%, 79.2%, and 73.6%,

respectively. The average conveyance efficiency of the main canal was 79.6% (Table 3). The average conveyance efficiency of the secondary and tertiary canals were 85.6% and 84.7%, respectively. The average conveyance efficiency of the canal was 56.83%. Food and Agriculture Organization FAO (2001), suggested that the conveyance efficiency of lined canal has to be 95% and from this the conveyance efficiency of the canal was poor. During the field investigation it was observed that, the water which was diverted from the head work was stagnant at some points in the canal and it takes a long duration of time to reach to the irrigation field. This low conveyance problem could be due to the design or technical problem during the construction of the canal.

The average canal loss per meter was 2×10^{-4} , 6.1×10^{-5} , and 1×10^{-4} m³/s at the head, middle, and tail reach of the main canal, respectively (Table 3). The average loss of the secondary and tertiary canals was 8.4×10^{-5} and 1.2×10^{-5} m³/s/m, respectively. The average canal loss was 9.2×10^{-5} m³/s/m. From this finding, it is clear that there was a conveyance efficiency variation with in the scheme at the head, middle, and tail reach. This could be due to a slope variation and there was unlined canal at the tail reach which has a relatively low conveyance of water.

Table 3. Conveyance Efficiency of the Scheme at the Head, Middle, and Tail Reach.

NO	L (M)	Q _{IN} (M ³ /S)	Q _{OUT} (M ³ /S)	EC (%) (Q _{OUT} /Q _{IN})	ΔQ (M ³ /S)	ΔQ/LT (M ³ /S/M)	CANAL REACH
1	18	0.042	0.037	87.4	6 × 10 ⁻³	4.3 × 10 ⁻⁴	Head reach
2	38	0.025	0.022	85.4	4 × 10 ⁻³	1.2 × 10 ⁻⁴	
3	49	0.024	0.021	86.4	3 × 10 ⁻³	6 × 10 ⁻⁵	
Average at head		0.030	0.026	86.4	4 × 10 ⁻³	2 × 10 ⁻⁴	
1	56	0.022	0.016	74.8	5 × 10 ⁻³	9.1 × 10 ⁻⁵	Middle reach
2	50	0.016	0.013	78.8	3 × 10 ⁻³	6.6 × 10 ⁻⁵	
3	50	0.011	0.009	83.8	1 × 10 ⁻³	2.7 × 10 ⁻⁵	
Average at middle		0.016	0.013	79.2	3 × 10 ⁻³	6.1 × 10 ⁻⁵	
1	50	0.015	0.012	84.0	3 × 10 ⁻³	6.5 × 10 ⁻⁵	Tail reach
2	75	0.007	0.006	78.6	1 × 10 ⁻³	1.5 × 10 ⁻⁵	
3	18	0.009	0.006	58.3	4 × 10 ⁻³	2.2 × 10 ⁻⁴	
Average at tail		0.011	0.008	73.6	3 × 10 ⁻³	1 × 10 ⁻⁴	
Average at main canal (Em)				79.6			
1	50	0.032	0.023	73.02	9 × 10 ⁻³	1.7 × 10 ⁻⁴	Secondary canal
2	30	0.021	0.020	94.56	1 × 10 ⁻³	3.8 × 10 ⁻⁵	
3	47	0.019	0.017	89.19	2 × 10 ⁻³	4.3 × 10 ⁻⁵	
Average at Secondary canal (Es)				85.6	4 × 10 ⁻³	8.4 × 10 ⁻⁵	
1	50	0.009	0.009	96.97	3 × 10 ⁻⁴	5.6 × 10 ⁻⁶	Tertiary canal
2	50	0.008	0.008	97.79	2 × 10 ⁻⁴	3.6 × 10 ⁻⁶	
3	100	0.007	0.004	59.46	2.7 × 10 ⁻³	2.7 × 10 ⁻⁵	
		0.008	0.007	84.74	1.1 × 10 ⁻³	1.2 × 10 ⁻⁵	
Average at Tertiary canal (Et)				83.4			
Overall conveyance efficiency = Em × Es × Et = 79.6 × 85.6 × 83.4 = 56.83%							

Application efficiency (E_a). The study revealed that the average application efficiency of the scheme was 59.2%, 33.42%, and 29.96% at the head, middle, and tail reach of the selected farmers field, respectively. The average application efficiency of the scheme was 40.87% (Table 4). The application efficiency shows that it is in a decreasing trend, showing that the water released from the head work was decreasing. Additionally, the slope of the land is not suitable for the application using furrow irrigation. The application efficiency was poor and below the recommended application efficiency of furrow irrigation. According to the soil conservation science the attainable application efficiency ranges from 55% to 70% (FAO, 1989). Similarly, FAO (2002) reports the application efficiency of furrow irrigation in

the range of 50% to 70%. Nature of the soil, crop specific management of farmers at the field, indigenous knowledge of the farmers and farmers commitment for applying the intended quantity of water were factors that cause the reduction of the application efficiency.

Storage efficiency (E_s). The storage efficiency of the scheme shows that, an average storage efficiency of 78.3%, 72.6%, and 83.2% at the head, middle, and tail reach, respectively. The average storage efficiency of the scheme was 78.04% (Table 5). It reveals that the storage efficiency of the scheme was relatively poor. The slope of the land was the major reason for the low performance of the storage efficiency. This may lead the

Table 4. Application Efficiency.

POINT	BEFORE IRRIGATION	AFTER IRRIGATION	ρ_B/ρ_W (DECIMAL)	W_S (MM)	W_F (MM)	E_A (%)	CANAL REACH
	θ_V (%)	θ_V (%)					
P-1	20.30	41.10	1.30	62.60	105.96	59.08	Head reach
P-2	22.80	45.80	1.40	68.80	105.96	64.93	
P-3	18.20	38.40	1.45	60.60	105.96	57.19	
P-4	18.40	38.00	1.33	58.90	105.96	55.59	
P-5	19.20	40.20	1.01	63.00	105.96	59.46	
Average at head reach						59.2	
P-1	21.80	44.20	1.29	67.00	203.50	32.92	Middle reach
P-2	20.90	45.10	1.52	72.60	203.50	35.68	
P-3	18.30	40.50	1.03	66.70	203.50	32.78	
P-4	24.30	45.80	1.38	64.60	203.50	31.74	
P-5	23.60	46.70	1.62	69.10	203.50	33.96	
Average at middle reach						33.42	
P-1	23.5	43.9	1.12	61.4	207.3	29.6	Tail reach
P-2	21.5	41.7	0.56	60.5	207.3	29.2	
P-3	22.9	43.2	1.25	61.1	207.3	29.5	
P-4	22.9	43.2	1.07	61.0	207.3	29.4	
P-5	22.8	45.0	1.33	66.5	207.3	32.1	
Average at tail reach						29.96	
Application efficiency (E_a) of the scheme						40.87	

Table 5. Storage Efficiency of The Water at the Tail, Middle, and Head Reach of the Scheme.

POINTS	DRY SOIL MOISTURE		ρ_B/ρ_W (DECIMAL)	M_{FCI}	M_{BI}	W_S (%)	W_N (%)	E_S (%)	CANAL REACH
	BI	AI							
P-1	22.99	61.87	1.30	40.70	19.90	62.40	81.12	76.92	Head reach
P-2	29.70	68.23	1.40	40.70	19.90	62.40	87.36	71.43	
P-3	25.90	51.32	1.45	40.70	19.90	62.40	90.48	68.97	
P-4	30.11	52.83	1.33	40.70	19.90	62.40	82.99	75.19	
P-5	40.15	65.56	1.01	40.70	19.90	62.40	63.02	99.01	
Average storage efficiency at the head reach								78.30	
P-1	39.82	65.88	1.29	44.45	21.79	67.98	87.69	77.52	Middle reach
P-2	33.54	72.19	1.52	44.45	21.79	67.98	103.33	65.79	
P-3	28.99	65.81	1.17	44.45	21.79	67.98	79.54	85.47	
P-4	36.03	67.43	1.38	44.45	21.79	67.98	93.81	72.46	
P-5	25.86	73.82	1.62	44.45	21.79	67.98	110.13	61.73	
Average storage efficiency at the middle reach								72.59	

(continued)

Table 5. (continued)

POINTS	DRY SOIL MOISTURE		ρ_B/ρ_W (DECIMAL)	M_{FCI}	M_{BI}	W_S (%)	W_N (%)	E_S (%)	CANAL REACH
	BI	AI							
P-1	21.50	54.86	1.12	43.40	22.70	62.10	69.55	89.29	Tail reach
P-2	21.07	91.20	1.15	43.40	22.70	62.10	71.42	86.96	
P-3	22.43	57.95	1.25	43.40	22.70	62.10	77.63	80.00	
P-4	22.45	62.88	1.18	43.40	22.70	62.10	73.28	84.75	
P-5	22.37	39.31	1.33	43.40	22.70	62.10	82.59	75.19	
Average storage efficiency at the tail reach								83.24	
Average storage efficiency of the scheme								78.04	
BI = before irrigation.								AI = after irrigation.	

crops under the water stress condition. Even though the storage efficiency was lower, there could be a positive attitude for the effective management of the water gradually. The current finding was in an agreement with Markos et al. (2019), who obtained a storage efficiency between 71% and 86% while evaluating the irrigation performance of Sanko Small Scale Irrigation Scheme and Tesfaye and Jemal (2020), while assessing the performance of storage efficiency at Wosha irrigation scheme which is in the range of 83% to 92.5%. The storage efficiency of the scheme reveals that it was performing well, since the minimum recommended storage efficiency of furrow irrigation was 63% (Levine, 1982; Raghuwanshi & Wallender, 1998).

Deep percolation ratio (DPR). The water applied to the field could be lost in the form of deep percolation and as a form of runoff. However some farmers control the runoff by practicing tied furrow system. Practically, throughout the Temsa scheme the farmers practice tied furrow system and hence they control the runoff. Hence, the water was lost or stored in the form of deep percolation below the root zone of the crop. The study result reveals that, the average deep percolation ratio was 42.83%, 66.86%, and 69.43% at the head reach, at the middle reach, and tail reach, respectively and the average deep percolation ratio of the scheme was 59.70% (Table 6). This result shows that there was a loss of water and the water was lost due to deep percolation, evapotranspiration and other technical application problems and also indicates over irrigation. According to FAO (1989) the water loss through deep percolation ratio could be more than 40%.

Distribution uniformity (DU). The average distribution uniformity of the scheme was 93.33% and it was 84.51%, 97.39%, and 98.09% at the head, middle, and tail reach of the scheme, respectively (Table 7). This distribution uniformity signifies that, the water was distributed uniformly throughout the

scheme. This was because the land was well prepared, the furrows were also made properly and at a relatively moderate length (less than 10 m). The distribution uniformity at the head was relatively lower, this could be because of the nature of the crops. In some vegetable crops (tomato in this case) since their leaf may cover the surface of the soil, the water could not be freely distributed and reach to all parts of the field. Hence it has an impact on the water distribution and its uniformity.

A distribution uniformity of 65% is considered as sufficient and if it is less than 30% the distribution was poor (Eisenhauer, 1997; FAO, 1992). According to San Joaquin Valley Drainage Implementation Program (1999), an effective distribution uniformity for furrow irrigation has to be between 80% up to 90%. Similarly, Dessalew and Dar (2016) obtained a distribution uniformity of above 90% while evaluating the irrigation performance of Bedene Alemetena irrigation scheme. There are also other scholars that obtained the distribution uniformity of a scheme above 90% which will create a positive attitude for the irrigation scheme sustainability (Tesfaye & Jemal, 2020). Based on the above justification it could be justified that the farmers were distributing the water to the field uniformly, even though there was a poor application efficiency.

Over all scheme efficiency. The poor application efficiency and low conveyance efficiency of the canal affected the overall scheme performance of the scheme. The result reveals that the overall efficiency of the scheme was 23.19% (Table 8). There was a courage that this application efficiency could be improved by training the farmers. Tesfaye and Jemal (2020) also obtained an overall scheme performance efficiency below 30% while evaluating the Wosha and Dodicha irrigation scheme, respectively. Similarly, Abo et al. (2024) obtained an overall scheme efficiency below 30% while evaluating the Bilate irrigation scheme. The overall irrigation efficiency values between 50% and 60% are good, 40% are reasonable, while 20% to 30% are poor (Rai et al., 2017). Therefore, the overall scheme

Table 6. Deep Percolation Ratio at the Head, Middle, and Tail Reach of The Scheme.

POINTS	HEAD REACH		MIDDLE REACH		TAIL REACH	
	EA (%)	DPR (%)	EA (%)	DPR (%)	EA (%)	DPR (%)
P-1	57.66	42.34	32.19	67.81	30.95	69.05
P-2	67.97	32.03	34.80	65.20	29.62	70.38
P-3	45.97	54.03	32.83	67.17	29.46	70.54
P-4	54.60	45.40	30.93	69.07	30.00	70.00
P-5	59.64	40.36	34.97	65.03	32.84	67.16
Average	57.17	42.83	33.14	66.86	30.57	69.43
Average deep percolation of the scheme						

Table 7. Distribution Uniformity at the Head, Middle, and Tail Reach of The Scheme.

NO	MAI (%)	MBI (%)	ρ_B/ρ_W (DECIMAL)	X1 (MM)	X2 (MM)	X3 (MM)	X4 (MM)	X5 (MM)	CANAL REACH
1	44.45	21.79	1.38	42.34	32.03	54.03	45.40	40.36	Head reach
	Total depth of water stored at each point			42.34	32.03	54.03	45.40	40.36	
	Descending order			54.03	45.40	42.34	40.36	32.03	
	Mean of lower quarter $\bar{X}Lq$ (mm)			36.20					
	Mean of infiltrated water depth $\bar{X}m$ (mm)			42.83					
	Distribution uniformity (Du) (%)			84.51					
2	29.97	18.46	1.33	67.81	65.20	67.17	69.07	65.03	Middle reach
	Total depth of water stored at each point			67.81	65.20	67.17	69.07	65.03	
	Descending order			69.07	67.81	67.17	65.20	65.03	
	Mean of lower quarter $\bar{X}Lq$ (mm)			65.12					
	Mean of infiltrated water depth $\bar{X}m$ (mm)			66.86					
	Distribution uniformity (Du) (%)			97.39					
3	43.40	22.70	1.17	69.05	70.38	70.54	70.00	67.16	Tail reach
	Total depth of water stored at each point			69.05	70.38	70.54	70.00	67.16	
	Descending order			70.54	70.38	70.00	69.05	67.16	
	Mean of lower quarter $\bar{X}Lq$ (mm)			68.11					
	Mean of infiltrated water depth $\bar{X}m$ (mm)			69.43					
	Distribution uniformity (Du) (%)			98.09					
Average DU of the scheme (%)			93.33						

Table 8. Over All Scheme Efficiency.

NO	INTERNAL INDICATOR	EFFICIENCY OF THE SCHEME (%)
1	Conveyance efficiency	56.73
2	Application efficiency	40.87
3	Storage efficiency	78.04
4	Deep percolation ratio	59.70
5	Distribution uniformity	93.33
Overall scheme efficiency (%)		23.19

performance of Temsa small scale irrigation scheme in the cropping season of 2016 was poor performance.

Performance of external indicators

Agricultural output indicators. The four basic agricultural output indicators of the scheme such as output per unit irrigated area, output per unit command area, output per unit irrigation diverted and output per unit water consumed gave 4,738.58(US\$/ha), 1,176.08 (US\$/ha), 1.66 (US\$/m³), and 0.89 (US\$/m³), respectively. The output per unit command area of a small-scale irrigation scheme was recommended between 1,223 and 9,436US\$/ha for different irrigation schemes (Degirmenci et al., 2003). Accordingly, the agricultural output of 1,176.08 US\$/ha was not in the recommended range as suggested by Degirmenci et al. (2003). This reveals that, the command area was not beneficial and the revenue farmers obtain in the cropping season was low. It could be improved through irrigating the whole or increasing the command area.

The output obtained per unit irrigated area from the scheme in the cropping season of 2016 E.C was 4,738.58 US\$/ha. It is one of the physical performance indicators which shows the revenue gained by applying a cubic meter of water through irrigation. The revenue obtained from irrigated area was relatively higher than that of the command area. This shows that irrigation is more advantageous in the scheme and if applied effectively the economic benefit could be obtained. Similarly, Degirmenci et al. (2003), reported that the output per unit irrigated area among various irrigation schemes was in the range of 308 to 5,771 US\$/ha. Accordingly, the output obtained per unit irrigated area from the Temsa irrigation scheme was in the recommended range. The output per unit irrigation diverted was 1.16 US\$/m³. This production shows that there was a more benefit from the irrigated scheme. Similarly, Abo et al. (2024) obtained approximately similar value of benefit at Bilate small scale irrigation scheme. The value of output per unit of irrigation could be between 0.03 and 2.21 US\$/m³ (Cakmak et al., 2004). Thus, the result of

output per irrigation delivered was in the recommended range of Cakmak et al. (2004) for the scheme.

The output per unit water consumed was 0.89 US\$/m³ for Temsa small scale irrigation scheme. Molden et al. (1998), suggested that the output per unit of water consumed for irrigation schemes could be in the range of 0.03 to 0.91 US\$/m³. Accordingly, the result of output per water consumed was in the recommended range of Molden et al. (1998). This indicates that the water use efficiency of the scheme was good and farmers are managing effectively based on the standard given.

Water supply indicators. The water supply indicators namely, relative water supply and relative irrigation supply were considered as one of the optimal criteria for the measurement of the adequacy of water for the crop. There values are evaluated as greater than one or less than one, showing over supply of water and under supply of water, respectively (Ayana & Awulachew, 2008). The relative irrigation supply (RIS) of Temsa scheme was 2.37 m³ (Table 9). Similarly, Wakena et al. (2023) obtained a relative irrigation supply of above 2.0 while evaluating the performance of the Degero and Gura Daso SSI schemes which were 2.28 and 2.06, respectively. This show that there was an adequate supply of irrigation to meet the crop water demand and even there was an excess supply of water to the field. This could be due to poor knowledge of agronomic practice, irrigation scheduling problem and unpredictable rainfall.

As shown in Table 9, the relative water supply (RWS) of the scheme was 1.39, showing that there was an excess delivery of water to the field and to the crop. Molden et al. (1998) reported that the relative water supply value of one is better than the higher or lower values for any irrigation scheme. Similarly, Ayana and Awulachew (2008) obtained water supply ratio ranging from 1.46 to 2.05 at Wonji irrigation scheme, indicating that the amount of water supplied at scheme level exceeded the estimated crop water requirement. This value could be improved through practicing agronomic practice, irrigation scheduling, maintaining the intake of the off taking canals at some points.

Water delivery capacity indicator (WDC). As shown in Table 10, the water delivery capacity of the canal at Tamsa irrigation scheme was 83%. This value is less than the expected capacity of the canal for delivering the intended quantity of water to the field. Water leakage due to the breakage of the structure lowered the delivering capacity of the canal. Due to this the water which was released from the head work take a long time to reach to the field.

Physical indicators

Physical indicators are related with the changing or losing irrigated land in the command area by different reasons. It could be determined by studying the irrigation ratio, and the sustainability of the scheme by comparing the initially and currently

Table 9. Performance Evaluation of The Water Supply Indicators (WSI) At Tamsa Scheme.

MONTHS	CROP WATER REQUIREMENT (M ³)										CWR (M ³)	P _{EFF} (M ³)	IWD (M ³)	DIW (M ³)	IWS (M ³)	RIS (M ³)	RWS (M ³)
	WHEAT	TOMATO	CABBAGE	ONION	WATER MELON	GREEN PAPER	CARROT	KCHAT	GREEN LETTUCE								
November	1,766	874	569	387	50	78	373	1,543	258	5,899	4,710	1,189	1,982	6,692	5.63	1.13	
December	6,797	1,330	757	618	102	111	562	2,770	343	13,390	5,146	8,244	13,739	18,885	2.29	1.41	
January	13,719	2,030	1,009	715	125	154	630	5,360	368	24,109	4,403	19,706	32,843	37,247	1.89	1.54	
February	11,186	2,103	1,083	674	82	151	141	5,974	35	21,428	5,405	16,022	26,704	32,109	2.00	1.50	
March	696	1,206	729	79	-	45	-	6,878	-	9,633	5,252	4,381	7,302	12,554	2.87	1.30	
April	-	-	-	-	-	-	-	5,284	-	5,284	4,931	353	588	5,519	15.65	1.04	
May	-	-	-	-	-	-	-	2,223	-	2,223	3,863	-	-	3,863	-	1.74	
Total	34,164	7,544	4,147	2,473	359	538	1,706	30,031	1,004	81,966	33,711	48,255	80,424	114,135	2.37	1.39	

Table 10. Performance of the Water Delivery Capacity Indicator.

NO	WATER DELIVERY INDICATORS	AMOUNT
1	Canal capacity to deliver water at system head (m ³ /s)	0.056
2	Maximum Kc of the crop	1.200
3	Peak consumptive demand (m ³ /s)	0.067
4	Water delivery capacity (%)	83

Table 11. Performance Evaluation of the Physical Indicators.

NO	PHYSICAL INDICATORS	AMOUNT
1	Command area (ha)	72
2	Irrigated cropped are (ha)	17.87
	Irrigation ratio	0.25
1	Currently irrigable area (ha)	42
2	Initially irrigated area (ha)	17.87
	Sustainability of irrigated area	0.43

irrigated area. In the current study the irrigation ratio and the sustainability of the irrigated area were 0.25 and 0.43, respectively (Table 11). The irrigation ratio was low due to the designing problem. When the command area was studied it was wide and up to 72 ha, but most of the lands were under the perennial crops such as coffee and other trees. However the farmers are not using the water for irrigating coffee because of the sloppy nature of their land and their previous experience at some areas of the scheme. Similarly, the sustainability of the scheme is also facing a challenge not because of the farmers interest but because of the suitability of the land for conventional irrigation. In addition to this since in the cropping year of 2016E.C, there was non-uniform distribution of rainfall especially at the beginning of the season, farmers didn't give a concern for irrigation and due to this their farm was left without farming.

Economic and financial indicators

For evaluating the economic and the financial indicators, gross return on investment, financial self-sufficiency, area, and water-based profitability were used for producing the obtained yield from the irrigation scheme as discussed below.

Gross return on investment. The Gross return on investment indicator considers the production and the total cost of infrastructure for the irrigation scheme. The total construction cost for the head work, canal, and ancillary structure was approximately 8 million Ethiopian birr (ETB). The standard gross value of production (SGVP) was determined on the currently irrigable area, crop type, and market price of the crop at the

local market the farmers could get. The SGVP at the current cropping season was 3,575,250.0 Ethiopian birr. Considering the above estimations, at the current the gross return on investment was 48%, showing that the revenue was low. Similarly, Behailu et al. (2004) reported a gross return between 18.25% and 42.1% while evaluating the small-scale Irrigation Schemes in community-based irrigation scheme in Tekeze basin of Tigray.

Financial self-sufficiency. The financial self-sufficiency result indicates how much of the revenue generated was used for operation and maintenance. It shows the ability of the users to manage the scheme without government support. In the scheme smaller maintenance tasks such as canal cleaning were done by the farmer themselves. The canal was maintained currently with the cost of 7,000,000 ETB. Since the total revenue obtained from the irrigation scheme in the cropping season was 3,329,550 Ethiopian Birr and maintenance cost was 7,000,000 Ethiopian birr and accordingly the financial self-sufficiency was 0.5. This shows that the farmers need access to credit for input and other costs in addition to the water pricing at the scheme in the future.

Area and water-based profitability. Both the area and water-based profitability of the scheme were evaluated. The result reveals that the area-based profitability ratio and the water-based profitability were 0.42 and 0.17, respectively. This shows that the scheme profitability was low and this could be, poor management of the water at the field and lack of awareness on producing wheat crop in the scheme. This could be improved through practicing irrigation scheduling for effective management of the field water, cultivating commercial crops based on farmers interest and crops that need low input cost and also through construction of micro basin on the sloppy areas.

Conclusion

Both the internal and external performance indicators were evaluated to determine the status of Temsa small scale irrigation scheme in the cropping year of 2016. From the internal indicators the ability of the canal to deliver water from the head work up to the field is in a good condition, except maintenance at the middle reach of the scheme. Other internal indicators which depend on the farmers ability and climatic condition are also good but for a better performance they have to be supported by the irrigation experts from the Gomma district. Farmer's practice of using a tied ridge has an advantage of controlling the water which could be lost in the form of run off, but still it needs an improvement on a sloppy land in the scheme to construct a micro-basin manually to save more water that could be lost.

Availability of water throughout the year and market accessibility near the scheme were the advantage of the scheme that encourage the farmers. However, the input costs for seed, fertilizer, herbicide and labor force were affecting the return from

the product. Hence it is better to provide access to credit for the sustainable production and improve the farmers income. Generally, in the cropping dry season of 2016 E.C the performance of the Temsa small scale irrigation scheme was poor based on the internally and external performance indicators taken. Therefore, Gomma district irrigation agronomy experts, extension workers and water user association have to integrate for the improvement of its performance in the next cropping season and a head.

Acknowledgements

The authors are thankful to the Ethiopian Institute of Agricultural Research and small-scale irrigation scheme project coordinators for providing financial support for conducting the study. They also express appreciation for the staff members of the Irrigation and Water Harvesting Research program technical assistants, namely Ms. Kalisa Aba Jihad, Mr. Aliyi Ababulgu, and Mr. Abdurazak Abazinab. We are also thankful for the staff members of the Soil and Plant Tissue Analysis Laboratory of Jimma Agricultural Research Center.

Declaration of Conflicting Interest

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The manuscript entitled "Performance Evaluation of Small-Scale Irrigation Scheme: A Case Study of Temsa Small Scale Irrigation Scheme of Goma District, Jimma Zone, South West Ethiopia" was a research conducted at Temsa scheme in the cropping season of 2016 E.C by the responsible researchers, namely Etefa Tilahun, Minda Tadesse, Addisu Asefa, and Hewan Tadesse. The necessary data were collected, analyzed and written by Etefa Tilahun, Minda Tadesse, Addisu Asefa, and Hewan Tadesse as a manuscript for publication. We hereby declare that this research is our original work, and all information in this document has been worked on responsibly and with ethical conduct. We also declare that, as required by these rules and procedures, all sources of materials that are not original to this work have been cited and duly acknowledged.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Availability of Data and Materials

The necessary data are available upon request from the corresponding author.

ORCID iDs

Etefa Tilahun  <https://orcid.org/0000-0002-7028-9255>

Minda Tadesse  <https://orcid.org/0000-0002-7964-5375>

REFERENCES

Abebe, N., & Kebede, E. (2020). *Determination of crop coefficients and water requirement of tomato at Werer*. Middle Awash Valley of Ethiopia.

- Abo, M. A., Assefa, S., & W/Michael, A. (2024). Performance evaluation of the Bilate and Furfuro irrigation schemes in Silti Zone, southern Ethiopia. *Journal of Engineering and Applied Science*, 71(1), 88.
- Acar, B. (2020). Water-yield relationships of lettuce plants for different irrigation strategies. *Mechanization in Agriculture & Conserving of the Resources*, 66(5), 177–180.
- Agmasie, M., Tewodros, A., Sisay, A., & Abdu, Y. (2022). Evaluating the performance of small-scale irrigation schemes in sub humid Ethiopian highlands. *Irrigation and Drainage*, 2022, 1–16.
- Allen, R. G., Pereira, L. S., Smith, M., Raes, D., & Wright, J. L. (2016). FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. *Journal of Irrigation and Drainage Engineering*, 131(1), 2–13.
- Al-Shammary, A. A. G., Kouzani, A. Z., Kaynak, A., Khoo, S. Y., Norton, M., & Gates, W. (2018). Soil bulk density estimation methods: A review. *Pedosphere*, 28(4), 581–596.
- Amdneh, M. W., & Gebul, M. A. (2023). Determination of water requirement and crop coefficient of wheat crop in Central Ethiopia. *MDPI*, 1–12. <https://doi.org/10.20944/preprints202310.1141.v1>.
- Amede, T. (2015). Technical and institutional attributes constraining the performance of small-scale irrigation in Ethiopia. *Water Resources and Rural Development*, 6, 78–91.
- Ashine, E. T., Tadesse Bedane, M., & Asefa Mengesha, A. (2024). Response of Carrot (*Daucus carota* L.) to supplementary irrigation under rain-fed agriculture at Jimma and Gera, Jimma Zone, South West Ethiopia. *Advances in Agriculture*, 2024(1), Article 3976619.
- Atroosh, K. B., & Al-Moayad, M. A. (2012). Water requirements of qat (*Catha edulis*) cultivation in the central highlands of Yemen. *Journal of Scientific Research*, 4(1), 77.
- Awulachew, S. B., & Ayana, M. (2011). Performance of irrigation: An assessment at different scales in Ethiopia. *Experimental Agriculture*, 47(S1), 57–69.
- Ayana, E. K., & Awulachew, S. B. (2008). Comparison of irrigation performance based on management and cropping types (Conference Papers h044064). International Water Management Institute.
- Behailu, M., Tadesse, N., Legesse, A., & Teklu, D. (2004). *Community based irrigation management in the Tekeze basin: Performance evaluation of small-scale irrigation schemes*. Mekelle University, ILRI, EARO.
- Bekele, D. (2011). *Linking irrigation farmers to markets: The case of Murtute irrigation farmers, Ethiopia*. Erasmus University.
- Berhane, G., Gebreyohannes, T., Martens, K., & Walraevens, K. (2016). Overview of micro-dam reservoirs (MDR) in Tigray (northern Ethiopia): Challenges and benefits. *Journal of African Earth Sciences*, 123, 210–222.
- Beshir, S. (2017). Review on estimation of crop water requirement, irrigation frequency and water use efficiency of cabbage production. *Journal of Geoscience and Environment Protection*, 5(7), 59.
- Bos, M. G., Murray-Rust, D. H., Merrey, D. J., Johnson, H. G., & Snellen, W. B. (1994). Methodologies for assessing performance of irrigation and drainage management. *Irrigation and Drainage Systems*, 7, 231–261.
- Bowan, P. A., Anzagira, L. F., Issahaku, Z., & Bang-Era, F. A. (2023). An evaluation of small-scale irrigation schemes infrastructure. *Journal of the Ghana Institution of Engineering*, 23(3), 8–17.
- Brabben, T., Angood, C., Skutsch, J., & Smith, L. (2004). *Irrigation can sustain rural livelihoods: Evidence from Bangladesh and Nepal*. HR Wallingford.
- Cakmak, B., Beyri bey, M., Yildirim, Y. E., & Kodal, S. (2004). Benchmarking performance of irrigation schemes: A case study from Turkey. *Irrigation and Drainage*, 53(2), 155–163.
- Dananto, M. U., & Alemu, E. (2014). Irrigation water management in small scale irrigation schemes: The case of the Ethiopian rift valley lake basin. *Environmental Resource Engineering and Management*, 1, 5–15.
- Degirmenci, H., Buyukcangaz, H., & Kuşcu, H. (2003). Assessment of irrigation schemes with comparative indicators in the Southeastern Anatolia Project. *Turkish Journal of Agriculture and Forestry*, 27(5), 293–303.
- Dessalew, T., & Dar, B. (2016). Performance evaluation of Bedene Alemtena Small Scale irrigation scheme in Hallaba Special Woreda, Southern Ethiopia. *Open Access Library Journal*, 3(2), 1.
- Dirirsa, G., Bekele, D., & Hordofa, T. (2017). Crop coefficient and water requirement of tomato (Melka Shola Variety) at Melkassa, central rift valley of Ethiopia. *Academic Research Journal of Agricultural Science and Research*, 5(5), 336–340.
- Eisenhauer, D. E. (1997). Irrigation performance measures: Efficiency and uniformity. *Journal of Irrigation and Drainage Engineering*, 123, 423–442.
- Embaye, T. A. G., Kahsay, G. H., Abadi, N., Kebede, M. M., & Dessie, D. T. (2020). Evaluation of water harvesting structures on agricultural productivity: The case of Tigray Region, Ethiopia. *Sustainable Water Resources Management*, 6, 1–14.
- Enyew, A., Tewabe, D., & Tsige, A. (2020). Determining the irrigation regime of watermelon at Koga and Rib irrigation schemes in Amhara Region, Ethiopia. *Cogent Food & Agriculture*, 6(1), Article 1730108.
- Feyen, J., & Zerihun, D. (1999). Assessment of the performance of border and furrow irrigation systems and the relationship between performance indicators and system variables. *Agricultural Water Management*, 40(2–3), 353–362.
- Food and Agricultural Organization. (1989). Irrigation scheduling. Irrigation water management (Training manual no. 4).
- Food and Agriculture Organization. (1992). CROPWAT: A computer program for irrigation planning and management (Irrigation and Drainage Paper. No. 46).
- Food and Agricultural Organization. (1998). Irrigation manual: Planning, development, monitoring and evaluation of irrigated agriculture with farmers participation.
- Food and Agricultural Organization. (2001). Training manual no 5, 2001. Irrigation water management: Irrigation methods (C. Brouwer, K. Prins, M. Kay, & M. Heibloem). Academia
- Food and Agriculture Organization. (2002). Irrigation manual: Planning, development monitoring and evaluation of irrigated agriculture with farmer participation. Volume II Module 7. Harare.
- Fufa, D. (2017). Technical performance evaluation of Ketar Medium Scale irrigation scheme, Southeast of Oromia regional state, Ethiopia. *Civil and Environmental Research*, 9(9), 13–21. <https://www.iiste.org>.
- Gebregziabher, G., Namara, R. E., & Holden, S. (2009). Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. *Agricultural Water Management*, 96(12), 1837–1843.
- Gelu, G., Dane, C., Ayza, A., & Habtewold, M. (2024). Optimal agricultural water allocation for enhanced productivity of hot pepper (*Capsicum annum* L) and economic gain: An experimental study from Southern Ethiopia. *Cogent Food & Agriculture*, 10(1), Article 2313045.
- Greaves, K. R. (2007). Quantifying and benchmarking irrigation scheme performance with water balances and performance indicators [Doctoral dissertation]. University of KwaZulu-Natal.
- Haile, A. T., Alemayehu, M., Rientjes, T., & Nakawuka, P. (2020). Evaluating irrigation scheduling and application efficiency: Baseline to revitalize Meki-Ziway irrigation scheme, Ethiopia. *SN Applied Sciences*, 2(10), 1710.
- Kassa, E. T., & Ayana, M. (2017). Hydraulic performance assessment of Tahtay Tsalit small scale irrigation scheme, Tigray, Ethiopia. *International Journal of Water Resources and Environmental Engineering*, 9(11), 254–263.
- Levine, G. (1982). *Relative water supply: An explanatory variable for irrigation systems* (Technical Report No. 6). Cornell University.
- Luo, W., Chen, M., Kang, Y., Li, W., Li, D., Cui, Y., Khan, S., & Luo, Y. (2022). Analysis of crop water requirements and irrigation demands for rice: Implications for increasing effective rainfall. *Agricultural Water Management*, 260, Article 107285.
- Markos, H., Shemelies, A., & Sirak, T. (2019). Performance evaluation of Sanko Small Scale irrigation scheme at Basketo special Woreda in SNNPR, Ethiopia. *Irrigation and Drainage Systems Engineering*, 8(233), 2.
- Mengiste, D., & Kidane, D. (2016). Assessment of the impact of small-scale irrigation on household livelihood improvement at Gubalafto District, North Wollo, Ethiopia. *Agriculture*, 6(3), 27.
- Michael, A. M. (2008). *Irrigation theory and practice* (2nd ed.) VIKAS Publishing House Pvt Ltd.
- Ministry of Water Resources. (2001). Irrigation development strategy (Component of the water sector development program) (Draft report).
- Moges, M. F. (2022). Indicators for evaluating the performance of small-scale irrigation schemes. *Journal of Agricultural Science and Botany*, 6(8), 136.
- Molden, D. J., Sakthivadivel, R., Perry, C. J., & De Fraiture, C. (1998). *Indicators for comparing performance of irrigated agricultural systems* (Vol. 20). IWMI.
- Raghuwanshi, N. S., & Wallender, W. W. (1998). Optimal furrow irrigation scheduling under heterogeneous conditions. *Agricultural Systems*, 58(1), 39–55.
- Rai, R. K., Singh, V. P., & Upadhyay, A. (2017). *Planning and evaluation of irrigation projects: Methods and implementation*. Academic Press.
- San Joaquin Valley Drainage Implementation Program. (1999). *Source reduction technical committee report*. Department of Water Resources.
- Smith, L. E. (2004). Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods. *International Journal of Water Resources Development*, 20(2), 243–257.
- Tamene, D., & Haile, A. (2021). Models comparative study for estimating crop water requirement and irrigation scheduling of maize in Metekel Zone, Benishangul Gumuz Regional State, Ethiopia. *International Journal of Agricultural Economics*, 6(2), 59.
- Tesfahunegn, G. B. (2014). Soil quality assessment strategies for evaluating soil degradation in Northern Ethiopia. *Applied and Environmental Soil Science*, 2014(1), Article 646502.
- Tesfaye, A., Bogale, A., Namara, R. E., & Bacha, D. (2008). The impact of small-scale irrigation on household food security: The case of Filitino and Godino irrigation schemes in Ethiopia. *Irrigation and Drainage Systems*, 22, 145–158.
- Tesfaye, H., & Jemal, K. (2020). Technical performance evaluation of small-scale irrigation scheme at Wondo Genet, Ethiopia. *American Journal of Science, Engineering and Technology*, 12(3), 128–134.
- Wakena, Y., Adeba, D., Mosisa, G., & Abebe, K. (2023). Performance evaluation of small-scale irrigation system in case of Degero and Gura Daso, Nejo District, West Wallaga, Oromia, Ethiopia. *Frontiers*, 3(3), 24–35.

- Wale, A., & Girmay, G. (2019). Determination of irrigation regime for hot pepper (*Capsicum annum* L.) in dry-land areas of Wag-Himra, North Eastern Amhara, Ethiopia. *Archives of Agriculture and Environmental Science*, 4(1), 101–108.
- Worldo meter. (2023). Elaboration of data by United Nations, Department of Economic and Social Affairs, Population Division. World population prospects: The 2022 revision (Medium-fertility variant). Retrieved July 8, 2024, from <https://www.Worldometers.info>
- Worqlul, A. W., Dile, Y. T., Schmitter, P., Jeong, J., Meki, M. N., Gerik, T. J., Srinivasan, R., Lefore, N., & Clarke, N. (2019). Water resource assessment, gaps, and constraints of vegetable production in Robit and Dangishta watersheds, Upper Blue Nile Basin, Ethiopia. *Agricultural Water Management*, 226, Article 105767.
- Zerssa, G., Feyssa, D., Kim, D. G., & Eichler-Lobermann, B. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture*, 11(3), 192.