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Authors: Chala, Mandefro, and Akamo, Alemitu

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Mandefro Chala[1] and Alemitu Akamo[2]

[1]Department of Hydraulic and Water Resources Engineering, College of Engineering, Wolaita Sodo University, Wolaita Sodo, Ethiopia. [2]Department of Civil Engineering, College of Engineering, Wolaita Sodo University, Wolaita Sodo, Ethiopia

ABSTRACT: Evaluating the existing irrigation system efficiency and proposing corrective actions are crucial for enhancing irrigation scheme performance. Hence, this study aimed to evaluate the effectiveness of the Ethana small-scale irrigation (SSI) scheme using a set of selected indicators. Relevant data were collected from field measurements and various documents. The scheme's performance was evaluated by determining water delivery, as well as internal and physical indicators. Flow rates at various off-takes (head, middle, and tail sections of the scheme) were recorded using a current meter and a 2″ Parshall flume. CROPWAT 8.0 computer software was used to determine water demand of selected crops. Data analysis was employed using empirical equations, simple descriptive statistics and GIS software. The result revealed that the overall efficiency of the scheme was 38.5% which is below the recommended value. The mean values of water delivery indicators were as follows: adequacy (0.85), delivery efficiency (0.81), equity (0.24), and dependability (0.29). Hence, adequacy, equity, and dependability were under fair conditions, while delivery efficiency was poor. The values of irrigation ratio (0.85) and sustainability of irrigated areas (0.93) showed that the current irrigated area is below the potential irrigable/command area. Generally, Ethana's small-scale irrigation scheme has been performing below expectations due to various factors. Therefore, it is recommended to improve awareness of irrigation water users regarding water delivery plan, operation, and maintenance of irrigation structures.

KEYWORDS: Efficiency, Ethana, evaluation, irrigation, performance

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CORRESPONDING AUTHOR: Mandefro Chala, Department of Hydraulic and Water Resources Engineering, College of Engineering, Wolaita Sodo University, Wolaita Sodo 138(4620), Ethiopia. Email: mande2000@gmail.com.

Introduction

In Ethiopia, it is evident that agriculture is the primary means of sustaining the livelihood of rural communities. Being Africa's second most populous nation, the country's smallholder rain-fed agricultural system would not be able to meet its food needs because it relies on rainfall, land degradation, fertility loss, and the effects of climate change (Berhe et al., 2022). According to Araya and Stroosnijder (2011), one of the primary causes of crop failure in rain-fed Ethiopian farming practices is soil moisture stress brought on by longer dry spells, shorter rainy seasons, and occasionally lack of rain.

Ethiopia has been using small-scale irrigation (SSI) to address food scarcity and improve the livelihoods of smallholder farmers. This strategy is seen as a way to mitigate the impact of climate change and generate employment opportunities in rural areas (Adela et al., 2019; Balana et al., 2020).

Performance evaluation is critical for every irrigation system to assess whether the system has achieved its initial goals and objectives. According to Adane et al. (2020), this evaluation is essential for obtaining the necessary information to enhance system management through corrective actions. Improving irrigation system performance through different interventions is seen as the main approach to enhancing crop productivity.

Research findings from Amede (2015) indicated that a number of irrigation projects are underperforming due to siltation problems, inadequate water management strategies, lack of consistent support from local institutions and design issues. Additionally, ineffective irrigation scheduling techniques have been identified as the primary barrier to the sustainability of irrigation schemes (Yohannes et al., 2019).

Performance evaluation using different indicators is important to identify limitations and enhance the irrigation system's overall productivity (Unal et al., 2004). Assessing the scheme-level performance of irrigation schemes has been attempted in Ethiopia (Akpalu & Bitew, 2017). Although several schemes are operating effectively, it has been noted that certain schemes have not fulfilled their original objectives (Ulsido & Alemu, 2016). Studies of this type are uncommon, especially in the southern region of Ethiopia. Prior research in the district utilized a limited set of indicators. However, evaluating the performance of irrigation schemes effectively requires considering a diverse range of performance indicators, rather than relying on a few isolated metrics. Therefore, the current study employed a different methodology and considered a more comprehensive range of performance indicators. With this goal in mind, this study was conducted to evaluate the performance of the Ethana SSI scheme using various indicators. The study provides valuable insights to the concerned stakeholders to make targeted improvements to the scheme, allocate resources more effectively, and adjust strategies based on a full understanding of performance.

Materials and Methods

Study area description

Ethana small-scale irrigation is located in Boloso Sore district, Wolaita zone, Southern Ethiopia. The scheme was established

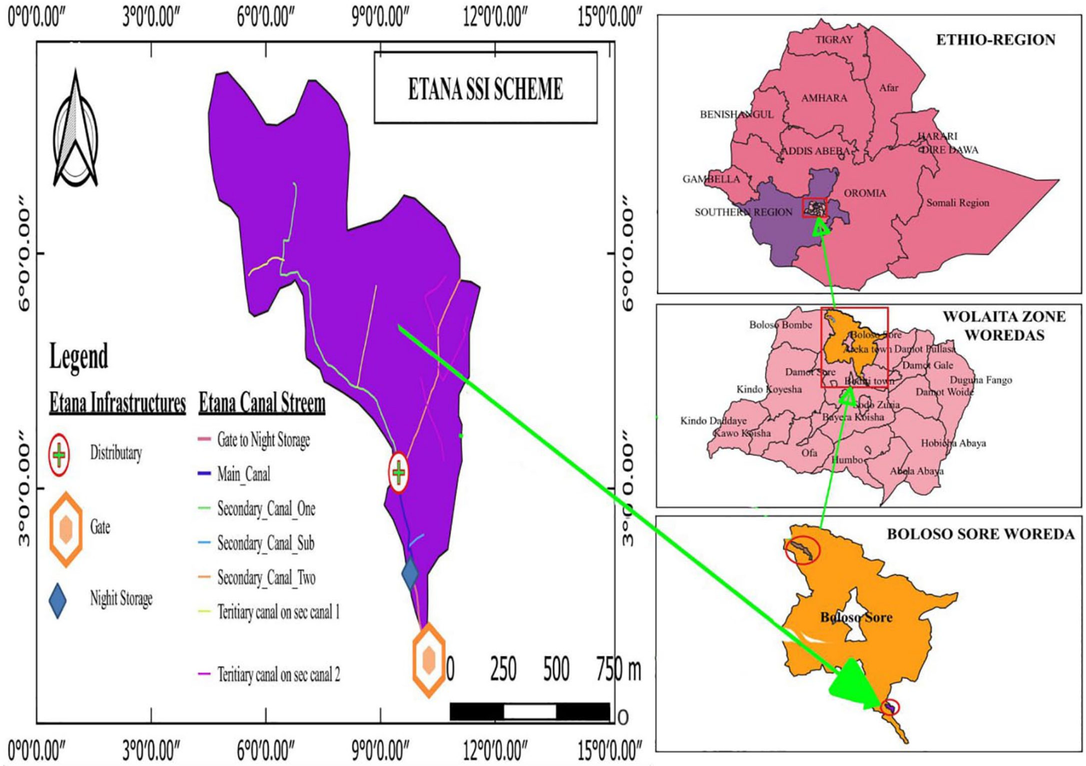

Figure1. Location map of Ethana small scale irrigation scheme.

by Southern Nations, Nationalities, and Peoples' Region Agricultural office in 2013. The Project area is situated on geographical grid of 6°24′06″N Latitude and 37°81′39″E Longitude and the average altitude of the area reaches to 2025 ma.s.l (Figure 1). The designed command area of the scheme was 60 ha. The rainfall pattern is bimodal, with a mean annual rainfall of 600 to 1600 mm. The mean monthly maximum and minimum temperatures are 29.3°C and 14.2°C, respectively. In the study area, the commonly used method of irrigation is furrow irrigation and major crops include cereals, vegetables, and tubers, with crop types varying seasonally. During the present study period, the dominant crops grown were wheat, potatoes, tomatoes, and cabbage.

Data collection

This study was conducted over one irrigation season, from October to December 2023. This period was selected as it coincides with the end of the rainy season. The data collection process involved taking measurements and conducting laboratory analyses. Data was collected from farmers located at the head, middle, and downstream areas of the command area. In addition to this, secondary data, including design documents, reports, and agronomic data, were gathered from district offices and FAO documents. Climatic data were obtained from a nearby meteorological station.

Soil sampling. In order to determine soil physical properties like soil texture, field capacity and permanent wilting point, composite soil samples from different depths have been collected using an Auger, and core sampler was used to collect undisturbed soil samples to determine bulk densities. Furthermore, soil infiltration rates were recorded using a double-ring infiltrometer at the head, middle, and tail reaches of the canals.

Flow rate measurement. The study employed a Parshall flume and a current meter to measure the flow rate. The water flow velocity in the main and secondary canals at specific locations was measured using a global current meter. A tape meter was used to measure the canal's dimensions. The discharge was calculated using the following formula.

$$Q = V * A \tag{1}$$

Where Q = discharge (m^3/s); A = flow cross sectional area (m^2); V = flow velocity (m/s)

The amount of water applied at each farmer's field was measured by installing Parshall flume at the selected offtakes. Head of the water and its discharge is related using equation (2).

$$Q = C * H^n \tag{2}$$

Where: Q = delivered discharge (m^3/s); H is water depth (m); C and n are constants.

Estimation of irrigation requirement

To determine how much water the major crops growing in the study area would require, the CROPWAT8 computer model was employed. Data on crops, soil, and climate were fed into the model. Agronomic and related data were adopted from FAO papers and the water users. The reference crop evapotranspiration (ETo) value was calculated using mean monthly climatic data: minimum and maximum temperature (°C), relative humidity (%), sunshine hours (hr), and wind speed (km/day). The crop evapotranspiration (ETc) was determined using ETo and crop coefficient (Kc).

$$\text{ETc} = \text{ETo x kc} \tag{3}$$

In addition, the net irrigation requirement (NIR) and gross irrigation requirement (GIR) were determined considering effective rainfall (Pe) and the overall irrigation efficiency (Eo).

$$\text{NIR} = \text{ETc} - \text{Pe} \tag{4}$$

$$\text{GIR} = \frac{\text{NIR}}{\text{Eo}} \tag{5}$$

The duty of each crop was determined by using equation (6).

$$D = \frac{GIR}{8.64} \tag{6}$$

Where: GIR = Gross irrigation requirement (mm day^{-1}) and 8.64 = Unit conversion factor

Then, the required discharge (Q_R) to be fed into each tertiary offtakes was obtained by multiplying the duty of the crop with the area covered by each crops.

$$Q_R = D * A \tag{7}$$

Where Q_R = required discharge (l s^{-1}); D = Duty of each crop (l s^{-1} ha^{-1}); A = area covered by each crop (ha).

Performance indicators measurements methods

In order to evaluate the effectiveness/performance of the scheme the following indicators were taken in to account.

Internal performance indicators. Application efficiency (E_a) is concerned with the actual storage of water in the root zone to satisfy crop water requirements relative to field water application.

$$\text{Ea} = \frac{\text{depth of water stored in the root zone}}{\text{Applied water depth}} \text{x100} \tag{8}$$

Conveyance efficiency (E_c) is the amount of water lost through seepage and evaporation in the network of conveyance system. Its value was calculated using equation (9).

$$\text{Ec} = \frac{\text{Discharge at the out flow}}{\text{Discharge at the inlet}} \text{x100} \tag{9}$$

Storage effciency (E_s) refers to the extent to which the water applied during irrigation has been stored in the root zone before irrigation.

$$\text{Es} = \frac{\text{Stored water depth}}{\text{required water depth}} \text{x100} \tag{10}$$

The overall scheme efficiency measures how well the complete physical system and operational choices work together to transport irrigation water to the intended field. It is computed by multiplying Ea with Ec (Irmak et al., 2011).

Performance indicators for water delivery. These indicators serve the purposes of determining if the water delivery service is safe or not (Molden & Gates, 1990).

Adequacy (P_A) measures whether the required flow is delivered to meet crop water demand or not.

$$P_A = \frac{QD}{QR} \tag{11}$$

Where: QD = delivered discharge and QR = required discharge

A value close to 1 indicates delivery of required water, whereas a value <0.8 presented inadequacy of water delivery.

Efficiency (P_F) reflects the capacity to save water by matching irrigation flows with crop demand.

$$P_F = \frac{QR}{QD} \tag{12}$$

P_F close to 1.00 implies efficient utilization of water in the system whereas if it is <0.70, it indicates inefficient utilization.

Equity (P_E) assesses fairness of water distributions and indicates spatial uniformity. It is expressed by equation (12).

$$P_E = \frac{1}{T} \Sigma \ CV_R \left(\frac{QD}{QR} \right) \tag{13}$$

Where CV_R is spatial coefficient of variation over a region R

P_E close to zero shows the greater degree of equity but PE becomes >0.25 implies low water distribution.

Dependability (P_D) shows the system's ability to deliver planned supply in a given period. It was computed by equation (14).

$$P_D = \frac{1}{R} \Sigma \ CV_T \left(\frac{QD}{QR} \right) \tag{14}$$

Where: CV_T is the temporal coefficient of variation of the ratio QD/QR over time T.

When P_D approaches to zero, it shows that the water delivery is working as planned for the duration. If it is >0.2, the opposite is true.

Table 1. Estimated Mean Values of Required and Delivered Flow of the Scheme ($m^3 s^{-1}$).

CANAL REACHES	OCTOBER		NOVEMBER		DECEMBER	
	QD	QR	QD	QR	QD	QR
Head	0.0078	0.0017	0.0077	0.0039	0.0069	0.0042
Middle	0.0057	0.0012	0.0049	0.0021	0.0041	0.0037
Tail	0.0050	0.0016	0.0037	0.0021	0.0026	0.0040

Note. QD and QR imply delivered and required discharge respectively.

Physical (area based) performance indicators. These indicators are associated with the shift or loss of irrigated land due to various reasons. The selected parameters were irrigation ratio (IR) and sustainability of irrigated area (SIA; Bos, 1997). The relevant data for estimation of IR and SIA were collected from the irrigation water users and district office.

$$\text{Irrigation ratio} = \frac{\text{Currently Irrigated area}}{\text{Irrigable(command) area}} \quad (15)$$

$$\text{Sustainability of irrigated area} = \frac{\text{Currently irrrigated area}}{\text{Design capacity}} \quad (16)$$

Data analysis

The delineation of map of the study area and irrigation scheme layout was done by using Arc GIS (ArcMap, version 10.3). Meteorological data, discharge data, and other selected indicators were also analyzed using Microsoft office Excel. Eventually, the selected performance indicators were computed.

Result and Discussion

Soil data analysis

The collected soil samples were examined for soil texture, bulk density, field capacity (FC), and permanent wilting point (PWP) in the Wolaita Sodo soil laboratory. According to the result, the scheme is clay loam dominant. The mean value of the bulk density was 1.04 g/cm^3. The determined values of FC, PWP, and total available soil moisture (TAM) were 40.36%, 23.77%, and 159.2 mm/m respectively. The infiltration rate was taken to be 1 cm/hr.

Estimation of required and delivered water

In order to measure the delivered depth of water, a two-inch Parshall flume was employed, and the delivered flow was estimated using equation (2). Furthermore, the irrigation requirement of the scheme was determined by taking into account climatic data, agronomic data, and the area covered by major crops, which totals 49.5 ha (comprising cabbage, wheat, tomato, and potato). Equation (6) was used to compute the required flow, and the resulting values at various locations are detailed in Table 1.

Performance indicators evaluation

Assessing the effectiveness of an irrigation system requires a thorough and extended evaluation, as its performance can fluctuate over time. A comprehensive assessment incorporating multiple indicators is crucial for obtaining a reliable measure of its efficiency and sustainability. Only through this detailed approach can we ensure the system's long-term effectiveness and make informed decisions about its management and improvements. In this study, standard performance indicators such as internal, water delivery and physical indicators were considered based on (Kartal et al., 2020; Molden & Gates, 1990) for a single irrigation season alone.

Indicators of internal performance. The effectiveness of irrigation is based on how well water moves through the canal, how the field is irrigated, how much is applied, and how evenly the application is distributed.

Application efficiency (Ea). The water application efficiency was calculated using equation (8). The application efficiency at the head, middle, and tail of the scheme was 57%, 52%, and 45% respectively, resulting in an overall application efficiency of 51.2%. According to FAO (1992), surface irrigation systems should aim for an achievable application efficiency of 50% to 70%. Therefore, it was found that the Ethana SSI scheme's application efficiency fell within the recommended range. However, there was inefficiency in managing irrigation water at the tail end. Similarly, the application efficiency of the Mugie and Fesas small scale irrigation schemes was found to be within the recommended values (Belay et al., 2023).

Conveyance efficiency (CE). The mean conveyance efficiency (CE) for lined canals was found to be 89.5%, while for unlined canals, it was 61%. The amount of water lost is influenced by the operation and maintenance of the canals, as well as the type of soil. Akkuzu et al. (2007) recommend a conveyance efficiency of 95% for lined canals and suggest that unlined canals with clay loam soils should aim for a conveyance efficiency of 80%. However, the conveyance efficiency of the schemes fell short of the required level due to a lack of controlling mechanisms, sediment deposits, and seepage losses. Similar results were also reported by other researchers (Abo et al., 2024).

Table 2. Adequacy Values of Water Distribution.

CANAL REACHES	LOCATION	MONTHS			TEMPORAL AVERAGE
		OCTOBER	NOVEMBER	DECEMBER	
Head	MP1	1	1	0.96	0.97
	MP2	1	1	0.88	
	MP3	1	1	0.9	
Middle	MP4	1	0.8	0.89	0.89
	MP5	0.88	0.97	0.92	
	MP6	1	0.85	0.74	
Tail	MP7	0.78	0.8	0.6	0.69
	MP8	0.78	0.8	0.36	
	MP9	0.74	0.82	0.54	
Spatial Ave.		0.91	0.89	0.75	0.85

Note. Where MP = measuring point.

Storage efficiency. The storage efficiency was determined considering soil moisture before and after irrigation application using equation (11). It ranges from 62% to 70% with a mean value of 66%. For furrow irrigation systems, a storage efficiency of 63% is advised (Raghuwanshi & Wallender, 1998). Consequently, the scheme has good water storage efficiency. This might be due to the nature of the soil (Clay loam). The current finding is in line with (Muluken, 2023) who reported the storage efficiency of 64.9% over the scheme at Delbo small scale irrigation scheme.

Overall scheme efficiency. This parameter was calculated by multiplying the efficiency of water application and conveyance (Irmak et al., 2011). It was determined to be 38.5%, which is low according to FAO recommendations. In line with this, the overall scheme efficiency of Haleku irrigation schemes was found to be 47.34% (Shiberu and Hailu, 2011). According to Magayane et al. (2004), a scheme efficiency of 50% to 60% is considered good, 40% is fair, and less than 40% is low.

Performance indicators for water delivery. Adequacy, efficiency, equity, and dependability were performance indicators for water delivery that Molden and Gates (1990) proposed.

Adequacy. Adequacy values were determined using equation (11). At the head, middle, and tail reaches of the scheme during the period of one irrigation season, the average temporal adequacy values were 0.97, 0.89, and 0.69, respectively. The spatial adequacy values were 0.91, 0.89, and 0.75 in October, November, and December, as shown in Table 2. The overall adequacy level of the scheme was 0.85, indicating fair condition according to Molden and Gates' (1990) standards. The findings revealed that the water supply was insufficient to meet the water requirements of crops due to water losses in the conveyance and distribution system. In line with this, Sibale et al. (2021) reported that the Nkhafi Irrigation Scheme had a fair Adequacy value.

Delivery efficiency. The delivery efficiency was computed using equation (12). Table 3 illustrates that the mean values of temporal delivery efficiency were 0.53, 0.91, and 1 at the head, middle, and tail reach of the scheme, respectively. Moreover, the mean values of spatial adequacy were 0.65, 0.78, and 1 in October, November, and December, respectively. The overall delivery efficiency was rated as fair (0.81) according to Molden and Gates (1990) standards. The results indicated inadequate monitoring of the water distribution systems and damaged flow control structures. Therefore, it is important to address operation and maintenance issues promptly. Similar results were obtained by Sibale et al. (2021).

Equity (PE) and dependability (PD). The equity at the selected tertiary offtakes was estimated using equation (13). In October, November, and December, the corresponding coefficients of variation were 0.16, 0.24, and 0.33, with the overall coefficient of variation being 0.24. As a result, the irrigation scheme was considered to be in fair standing according to Molden and Gates' (1990) guidelines. The results indicated that the water delivery system was not as uniform as expected. To improve the equity of the scheme, controlling the flow and implementing a proper water delivery plan would be beneficial.

To evaluate the dependability/reliability of the scheme equation (14) was used. The result showed that the dependability of the scheme was 0.29, indicating poor performance according to Molden and Gates (1990) standards. This indicates that water is not being delivered to the fields at the appropriate times, which can be attributed to an absence of a well-organized strategy for water delivery, water losses, and issues with flow regulators. In order to improve water delivery

Table 3. Delivery Efficiency of the Water Distribution.

CANAL REACHES	LOCATION	MONTHS			TEMPORAL MEAN
		OCTOBER	NOVEMBER	DECEMBER	
Head	MP1	0.30	0.46	0.99	0.53
	MP2	0.19	0.4	1.00	
	MP3	0.23	0.14	1.00	
Middle	MP4	0.16	0.99	0.99	0.91
	MP5	1.00	0.99	1.00	
	MP6	1.00	1.00	0.99	
Tail	MP7	1.00	0.99	1.00	0.99
	MP8	1.00	0.99	1.00	
	MP9	1.00	1.00	0.99	
Spatial mean		0.65	0.78	1.00	0.81

Table 4. Equity and Dependability Values.

CANAL R.	LOCATION	MONTHS			TEMPORAL AVE.	*SD*	CVT
		OCTOBER	NOVEMBER	DECEMBER			
Head	MP1	1	1	0.96	0.97	0.11	0.11
	MP2	1	1	0.88			
	MP3	1	1	0.9			
Middle	MP4	1	0.8	0.89	0.89	0.27	0.31
	MP5	0.88	0.97	0.92			
	MP6	1	0.85	0.74			
Tail	MP7	0.78	0.8	0.6	0.69	0.32	0.46
	MP8	0.78	0.8	0.36			
	MP9	0.74	0.82	0.54			
Spatial mean	0.91	0.89	0.75				
SD	0.15	0.21	0.25				
CVR	0.16	0.24	0.33				

Note. Where *SD* is standard deviation and *CV* is coefficient of variation.

performance, regular maintenance work needs to be carried out throughout the entire canal network. These findings align with the research by Agide et al. (2016), which emphasized the importance of maintaining the system to improve water conveyance and distribution (Table 4).

Physical performance indicators. Data such as irrigable/command area (66 ha), design capacity (60 ha), and currently irrigated area (56 ha) were collected from farmers and Boloso Sore district water, irrigation, and mine office. The irrigation ratio (IR) and sustainability of irrigated area (SIA) were estimated using equations (15) and (16).

Irrigation ratio. The computed value of irrigation ratio of the Ethana SSI scheme was 0.85. It implies that of the total irrigable land 15% was not irrigated. Misuse of irrigation water, high price of inputs supply, and absence of consistent support from the district were the reasons not to irrigate more. In line with this, Dejen et al. (2012) reported that the Golgota irrigation scheme had a lower irrigation ratio.

Sustainability of irrigated area (SIA). The SIA (Sustainability of irrigated area) of the Ethana irrigation scheme was 0.93. This suggests that initially irrigated fields are being abandoned, indicating a 7% reduction in irrigable area. The major causes contributing to this shrinkage were water scarcity, inadequate irrigation infrastructure maintenance, and market problems. On the contrary, Dejen et al. (2012) reported SIA of the Golgota SSI scheme to be 1.22. Thus, the irrigated area of the scheme has increased by about 22%.

Conclusion

The purpose of performance evaluation is to determine the scheme's current status and suggest areas for improvement. In the present study, to evaluate the performance of the Ethana SSI scheme, performance indicators such as internal (application, conveyance, storage, and overall efficiency), water delivery (adequacy, delivery efficiency, equity, and dependability), and physical (IR and SIA) were considered.

During the field visit, it was observed that the water users' methods for managing their irrigation water were ineffective, and some of the structures were not functioning properly. The overall efficiency of the scheme was found to be 38.5%, which is below the recommended standard. Adequacy, equity, and dependability were in fair condition, but delivery efficiency was poor. Based on the irrigation ratio (0.85) and the sustainability of irrigated area (0.93) values, there is currently less irrigated land than the potential irrigable/command area available. The limited water supply, lack of water distribution infrastructure, and market issues were identified as the main causes of the reduction in irrigated land.

Overall, Ethana small-scale irrigation scheme has been underperforming. This can be attributed to several factors including an insufficient water delivery plan, unauthorized water abstraction from the upstream area of the scheme, water loss due to seepage, and lack of timely maintenance. To address these issues, timely maintenance, operation and management activities should be carried out by concerned stakeholders including empowering the water users association.

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Authors Contributions

M.C: Conceptualization, data analysis, editing, review, writing, and supervision. AA: Conceptualization, Materials preparation, Data collection, analysis, and writing.

Declaration of Conflict of Interests

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ORCID iD

Mandefro Chala https://orcid.org/0009-0008-5159-9144

REFERENCES

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), 1–28. https://doi.org/10.1186/s44147-024-00419-5

Abrha, B. H., & Chen, Y. (2017). Analysis of physico-chemical characteristics of effluents from beverage industry in Ethiopia. *Journal of Geoscience and Environment Protection*, 5, 172–82. https://doi.org/10.4236/gep.2017.56016

Adane, Biniam, Fiseha Behulu, And, and Dawud Temam(2020). Performance Assessment of Small Scale Irrigation Schemes: A Case Study of Upper Blue Nile, East Dangila Woreda, Ethiopia." *Irrigation and Drainage Systems Engineering* 9 (4): 7–10. https://doi.org/10.37421/idse.2020.9.247.

Adela, F.A., Aurbacher, J. & Abebe, G.K. (2019). Small-scale irrigation scheme governance - poverty nexus: evidence from Ethiopia. *Food Security* 11, 897–913. https://doi.org/10.1007/s12571-019-00953-8

Agide, Z., Haileselassie, A., Sally, H., Erkossa, T., & Schmitter, P. S. (2016). *Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia, diversity and lessons across schemes, typologies and reaches*. Food and Agriculture Organization.

Akkuzu, E., Ünal, H. B., & Karataş, B. K. (2007). Determination of water conveyance loss in the menemen open canal irrigation network. *Turkish Journal of Agriculture and Forestry Volume*, 31(1), 11–22.

Akpalu, W., & Bitew, W. T. (2017). *Externalities and foreign capital in aquaculture production in developing countries*. UN University World Instiute for Development Economics Research.

Amede, T. (2015). Technical and institutional attributes constraining the performance of small-scale irrigation in Ethiopia. *Water Resources and Rural Development*, 6, 78–91. https://doi.org/10.1016/j.wrr.2014.10.005

Amsalu, A., & De Graaff, J. (2006). Farmers' views of soil erosion problems and their conservation knowledge at beressa watershed, central highlands of Ethiopia. *Agriculture and Human Values*, 23, 99–108. https://doi.org/10.1007/s10460-005-5872-4

Araya, A., & Stroosnijder, L. (2011). Assessing drought risk and irrigation need in Northern Ethiopia. *Agricultural and Forest Meteorology*, 151(4), 425–436. https://doi.org/10.1016/j.agrformet.2010.11.014

Balana, B. B., Bizimana, J. C., Richardson, J. W., Lefore, N., Adimassu, Z., & Herbst, B. K. (2020). Economic and food security effects of small-scale irrigation technologies in Northern Ghana. *Water Resources and Economics*, 29, Article 100141. https://doi.org/10.1016/j.wre.2019.03.001

Belay, A. M., Assefa, T. T., Belay, S. A., & Yimam, A. Y. (2023). Evaluating the performance of small-scale irrigation schemes in subhumid Ethiopian highlands. *Irrigation and Drainage*, 72(1), 224–239.

Berhe, G. T., Baartman, J. E. M., Veldwisch, G. J., Grum, B., & Ritsema, C. J. (2022). Irrigation development and management practices in Ethiopia: A systematic review on existing problems, sustainability issues and future directions. *Agricultural Water Management*, 274, Article 107959. https://doi.org/10.1016/j.agwat.2022.107959

Bos, M. G. (1997). Performance indicators for irrigation and drainage. *Irrigation and Drainage Systems*, 11(2), 119–37. https://doi.org/10.1023/A:1005826407118

Dejen, Z. A., Schultz, B., & Hayde, L. (2012). Comparative irrigation performance assessment in community-managed schemes in Ethiopia. *African Journal of Agricultural Research*, 7(35), 4956–4970. https://doi.org/10.5897/AJAR11.2135

FAO. (1992). Irrigation manual module 7 FAO 2002. Surface irrigation systems planning, design,operation and maintenance (Vol. II). Fontline Electronic Publishing. https://sswm.info/sites/default/files/reference_attachments/FAO1992Irrigation-manual.pdf

Irmak, S., Odhiambo, L. O., Kranz, W. L., & Eisenhauer, D. E. (2011). Irrigation efficiency and uniformity, and crop water use efficiency. *Biological Systems Engineering:Papers and Publications*, 451(EC732), 1–29.

Kartal, S., Değirmenci, H., & Arslan, F. (2020). Assessment of irrigation schemes with performance indicators in Southeastern irrigation district of Turkey. *Journal of Agricultural Sciences*, 26(2), 138–146. https://doi.org/10.15832/ankutbd.512677

Magayane, M., Makarius, M., & Lankford, B. (2004). *Irrigation efficiency and productivity manual: Tools for irrigation professionals and practioners*. Irrigation Efficiency and Productivity Workshop, Mbeya.

Molden, D. J., & Gates, T. K. (1990). Performance measures for evaluation of irrigation water delivery systems. *Journal of Irrigation and Drainage Engineering*, 116(6), 804–823.

Muluken, D. (2023). Evaluation of Delbo small scale irrigation scheme performance Southern, Ethiopia. *Journal of Ecology & Natural Resources*, 7(4), Article 000359.

Raghuwanshi, N. S., & Wallender, W. W. (1998). Optimal furrow irrigation scheduling under heterogeneous conditions. *Agricultural Systems*, 58(1), 39–55. https://doi.org/10.1016/S0308-521X(98)00030-4

Shiberu, E., & Hailu, H. (2011). *Performance evaluation of small scale irrigation schemes in Adami Tullu Jido Kombolcha Woreda, Central Rift Valley of Ethiopia* (p. 75). Haramaya University.

Sibale, D., Mwenelupembe, G., Chikabvumbwa, S., & Chisale, S. (2021). Evaluation of water delivery performance of Nkhafi irrigation scheme in Dowa District, Malawi, Africa. *Computational Water, Energy, and Environmental Engineering*, 10(3), 95–107.

Ulsido, M. D., & Alemu, E. (2016). Irrigation water management in small scale irrigation schemes: Rift Valley Lake Basin. *Environmental Research,Engineering and Management*, 1(67), 4–15. https://doi.org/10.5755/j01.erem.67.1.6240

Unal, H. B., Asik, S., Avci, M., Yasar, S., & Akkuzu, E. (2004). Performance of water delivery system at tertiary canal level: A case study of the Menemen Left Bank Irrigation System, Gediz Basin, Turkey. A*gricultural Water Management*, 65, 155–171.

Yohannes, D. F., Ritsema, C. J., Eyasu, Y., Solomon, H., van Dam, J. C., Froebrich, J., Ritzema, H. P., & Meressa, A. (2019). A participatory and practical irrigation scheduling in semiarid areas: Northern Ethiopia. *Agricultural Water Management*, 218, 102–14. https://doi.org/10.1016/j.agwat.2019.03.036