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Research Article

Evaluating the Irrigation Water Delivery Performance of Koftu Small-Scale Irrigation, Ethiopia

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Abstract

This study evaluates the performance of small-scale irrigation schemes in Koftu, Ethiopia, in enhancing water resource utilization. Employing a range of methods, including conversations, flow measurements, household surveys, and literature searches, the research assesses the performance of the irrigation schemes using performance indicators for outputs, output delivery, and financial performance. To estimate crop water requirements, the CROPWAT model was used. The results show that the average relative water and irrigation supply were 2.06 and 2.47, respectively. The output per unit-controlled area was 21094.43 US$/ha, while the output per unit-cultivated area was 11212.33 US$/ha. The study also found that the irrigation schemes had a high-water productivity ratio of 2.10 US dollars per m3 of output and 1.02 US dollars per m3 of supply per unit of water used. Additionally, the schemes demonstrated high financial self-sufficiency due to low operation and maintenance costs. Overall, the findings suggest that the small-scale irrigation schemes in Koftu, Ethiopia, have successfully enhanced water resource utilization and improved both land and water productivity. Using performance indicators provides a valuable tool for identifying areas for improvement in irrigation schemes.

Keywords: Small-Scale Irrigation, Water Resource Utilization, Performance Indicators, Crop Water Requirements, Financial Self-Sufficiency.

1. Introduction

1.1. Background

Ethiopia's abundant water resources present a significant opportunity for agricultural development [1, 2]. However, a critical issue is the lack of well-organized research on integrated water resource management and finance, which has limited the utilization of these resources for agriculture. This challenge is compounded by inadequate water distribution within various sectors, stemming from insufficient hydrological knowledge, underutilized water allocation methods, and a lack of clarity regarding allocation priorities in sub-basins [3]. Despite extensive efforts to harness the potential of the country's major river basins, there remains a considerable gap in agricultural and irrigation development [4, 5].

Small-scale irrigation holds promise as a pivotal intervention to enhance water resource utilization and increase land productivity in Ethiopia [6, 7]. However, its expansion has fallen short of its potential benefits. Conventional and modern irrigation methods are employed on a mere 10% to 12% of the total potential irrigable land, with just 0.64 million hectares out of 5.3 million hectares currently in use. The underutilization exacerbates Ethiopia's challenge of producing multiple farming seasons to meet its food demand due to the erratic nature of rainfall, which has become increasingly frequent and intense, leading to agricultural setbacks [8-11].

The promotion of water-related technologies, particularly irrigation, is contingent on the availability of water and land resources to address these deep-rooted challenges. Unfortunately, little effort has been devoted to monitoring and evaluating the effectiveness of existing irrigation schemes, leaving a significant gap in understanding their performance and potential areas for improvement [12-14].

Ethiopia's irrigation landscape comprises three types: large-scale (above 3,000 hectares), medium-scale (200-3,000 hectares), and small-scale (less than 200 hectares) [15, 16].

Small-scale irrigation dominates food production due to landholding policies and demographics, making it crucial for rural food self-sufficiency [17, 18]. These community-managed irrigation schemes have experienced substantial growth over the past two decades, marking a transition from traditional reliance on rainfall to a more intensive irrigated agriculture approach [19-21]. This shift has not only contributed to the food security of smallholder farmers but has also alleviated poverty among the rural population [22, 23]. However, these small-scale irrigation facilities confront the range of challenges, including issues related to irrigation water management, scheduling, water conservation, measurement techniques, and facility operation and maintenance [24-26].

Despite the importance of small-scale irrigation schemes, assessing their effectiveness in achieving their objectives is not straightforward [27]. A comprehensive evaluation is crucial to identify the root causes of issues and propose solutions to enhance their performance [28]. The study seeks to address these issues, primarily focusing on the efficient utilization of limited resources in small-scale irrigation schemes and identifying effective management practices to improve their performance [28-30].

1.2. Problem Statement and Research Gap

The critical problem at the heart of this research is the underutilization of Ethiopia's vast water resources for agricultural purposes due to the lack of well-organized research on integrated water resource management and finance [8, 31]. This problem is further compounded by the inadequate distribution of water resources, the under-implementation of water allocation methods, and the absence of a clear understanding of allocation priorities in sub-basins, resulting in an untapped potential for agriculture and irrigation [32].

The existing research landscape also reveals a significant gap in the monitoring and evaluation of the effectiveness of small-scale irrigation schemes, particularly in addressing issues related to irrigation water management, scheduling, water conservation, measurement techniques, and facility operation and maintenance [1, 33].

To bridge this gap, the study aims to assess the performance indicators of limited resources in small-scale irrigation schemes, identify effective management practices, and provide recommendations to enhance their systems and management practices [17]. By These community-managed irrigation schemes have experienced substantial growth over the past two decades, marking a transition from traditional reliance on rainfall to a more intensive irrigated agriculture approach [19-21]. This shift has not only contributed to the food security of smallholder farmers but has also alleviated poverty among the rural population [22, 23]. However, these small-scale irrigation facilities confront the range of challenges, including issues related to irrigation water management, scheduling, water conservation, measurement techniques, and facility operation and maintenance [24-26].

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1.3. Data Analysis and Interpretation

Water Supply Indicators: The major goal of the study of the water supply's performance was to determine whether it was doing enough to meet demand or crop water needs. The following is a list of the indicators that were utilized in this study to gauge water delivery performance:

$$\text{Relative water supply (RWS)} = \frac{\text{Total Water supply}}{\text{Total crop water demand}} \quad (1)$$

Where, Total water supply equals effective rainfall plus irrigation supply in (m^3), Crop water demand is calculated using the CROPWAT model for a specific cropping pattern and crop intensity. It is equal to the potential evapotranspiration or the evapotranspiration under well-water circumstances for each crop in (m^3).

$$\text{Relative irrigation supply (RIS)} = \frac{\text{Irrigation Supply}}{\text{Irrigation demand}} \quad (2)$$

Where irrigation demand is the difference between crop ET and effective rainfall in (m3) and irrigation supply is merely the surface diversion for irrigation (m^3).

Output Indicators: Production, or the idea that where there is input, there should be output, is irrigation's primary goal. Water and irrigation infrastructure, together with other agricultural inputs, are therefore used in irrigated agriculture, and the finished product can be measured in terms of productivity (yield in tons or its monetary value in US$) per unit of land and water resources used. The output per unit of land and per unit of water are the fundamental metrics used to assess the output performance of irrigation schemes.

Agricultural Output: It was used to assess the productivity of the land, represented as production per unit of land if land is a restriction concerning water. The productivity of the land is expressed by two indices.

$$\text{The output per unit actual harvested area}\left(\frac{\text{US\$}}{\text{ha}}\right) = \frac{\text{value of total crop production}}{\textit{Total actual command area harvested}} \quad (3)$$

$$\text{The output per designed command area}\left(\frac{\text{US\$}}{\text{ha}}\right) = \frac{\text{value of total crop production}}{\text{designed command area}} \quad (4)$$

Water Productivity: This statistic assesses the economic impact of irrigation in relation to water usage, a finite resource. Two metrics can be used to assess water productivity, which can be stated in terms of monetary values per unit of water.

$$\text{The output per unit water supplied}\left(\frac{\text{US\$}}{\text{m}^3}\right) = \frac{\text{value of total crop production}}{\text{total volume of water supplied}} \quad (5)$$

$$\text{The output per unit water consumed}\left(\frac{\text{US\$}}{\text{m}^3}\right) = \frac{\text{value of total crop production}}{\text{total volume water consumed by ET}} \quad (6)$$

Where, volume of water consumed by ET (m^3) is the actual evapotranspiration of crops.

Financial indicators: The following two financial metrics, which were utilized in this study to assess the scheme's financial performance, are:

$$\text{Gross return on investment (\%)} = \frac{\text{gross value of production (GVP)}}{\text{Cost of irrigation infrastructures}} \quad (7)$$

The following two financial metrics, which were utilized in this study to assess the scheme's financial performance, are:

GVP was first calculated by gathering information from the schemes through direct questionnaires on the area under each crop, the related yield of the crops, and their price per hectare of land. Then, the offices collected the total yield and prices of the crops sold locally, and these were cross-checked against the information obtained from user interviews. The GVP was therefore determined as the total of the individual values of each crop.

$$\text{GVP} = [\textstyle\sum (\text{Ai Yi Pi})] \quad (8)$$

Where Ai is the area of the irrigated crop, Yi is the yield, and Pi is the price of the irrigated crop on the local market.

The cost of irrigation infrastructure is calculated as present net worth (PNW) using the average interest rate of the service years, considering the cost of the irrigation water delivery system with reference to the same years as the GVP.

$$\text{PNW} = \text{P} \times (1 + i)^n \quad (9)$$

P = average investment cost (ETB), i = average interest rate in the service years (percent), and n = number of service years, where PNW = current net value.

$$\text{Financial self} - \text{sufficiency (FSS)} = \frac{\text{Revenue from irrigation service fees}}{\text{Total O \& M expenditure}} \quad (10)$$

Whereas total O&M expenditure is the sum spent locally on operations and maintenance, revenue from irrigation is the revenue derived from fees or other locally produced income.

Table 1: Annual Irrigated Area, Crop Area Coverage, Water Requirements, Crop Yields and Production Value of Koftu Irrigation Schemes.

Irrigation year	Crop type	Irrigated Area (ha)	CWR (mm)	NIR (mm)	yield (qt /ha)	Yield (quintal)	Production Valeu (US$)	US$/ha
2019/20	Tomato	40	549.1	465.9	145	5800	580000	14500
	Onion	16	483	387.3	115	1840	306666.7	19166.7
	Cabbage	22	621.5	501.6	120	2640	352000	16000
	Potato	8	472.8	414.3	75	600	40000	5000
	Maize	6	411.1	359.8	70	420	35000	5833.3
	Pepper	2	436.3	384.9	55	110	22000	11000
	Total	94	2973.8	2513.8	580	11410	1335666.7	14209.2
2020/21	Tomato	36	549.1	465.9	145	5220	391500	10875
	Onion	20	483	387.3	115	2300	287500	14375
	Cabbage	18	621.5	501.6	120	2160	216000	12000
	Potato	7	472.8	414.3	75	525	26250	3750
	Maize	6	411.1	359.8	70	420	26250	4375
	Pepper	4	436.3	384.9	55	220	33000	8250
	Total	91	2973.8	2513.8	580	10845	980500	10774.7
2021/22	Tomato	32	549.1	465.9	145	4640	278400	8700
	Onion	24	483	387.3	115	2760	276000	11500
	Cabbage	24	621.5	501.6	120	2880	230400	9600
	Potato	12	472.8	414.3	75	900	36000	3000
	Maize	4	411.1	359.8	70	280	14000	3500
	Pepper	2	436.3	384.9	55	110	13200	6600
	Total	98	2973.8	2513.8	580	11570	848000	8653.1
Average		94.3	2973.8	2513.8	580	11275	1054722.2	11180.8

3. Results & Discussion

3.1. Water Delivery Performance

The Relative Water Supply (RWS) and Relative Irrigation Supply (RIS) indicators were used to evaluate the sufficiency of water supply for meeting crop water demand in the irrigation system [33-35]. These indicators determine whether there is an abundance or scarcity of water in a particular irrigation system. Optimal service delivery conditions are attained when RWS and RIS are both equal to 1. A value less than or greater than one for either indicator denotes a shortage or excess of available water for irrigation, respectively [29]. RWS values of at least 0.8, as per, may indicate that water-related problems do not exist in an irrigation scheme. Table 2 presents the average annual RWS and RIS values obtained [35].

The calculation of this indicator involved the use of diverted irrigation quantity, total crop water and irrigation demand, total precipitation, and crop irrigation demand, which was determined using the CROPWAT model for a particular irrigation season and cropping pattern. For the Koftu SSI scheme, the RWS values for the irrigation seasons 2019/20, 2020/21, and 2021/22 were 2.02, 2.12, and 2.04, respectively, with an average of 2.06, as shown in Tables 1-3. This indicates that the water accessibility was proportional to the crop water demand, and the values of the scheme indicated that the overall water supply exceeded the total agricultural water demand. RWS values greater than one imply that the water provided to the farmland satisfies the crop needs, while values less than one imply water scarcity [35].

The Koftu irrigation scheme's relative water supply is consistent with previous studies conducted in Ethiopia and globally. Hassen found the relative water supply ratios for the Betu Degega and Doni schemes to be 2.32 and 2.24, respectively. In contrast, Dejen research on the Golgota and Wedecha schemes revealed lower relative water supply values of 1.32 and 1.25, respectively [24, 36]. The Koftu scheme's results were better than Dejen's, but within the range of relative water supply values of 0.8 to 4 observed in 18 systems across 11 countries [35].

The Relative Irrigation Supply (RIS) is calculated by dividing the irrigation supply by irrigation demand, which is the total water demand minus effective rainfall. The scheme's RIS values were 2.42, 2.54, and 2.45 in the irrigation years 2019/20, 2020/21, and 2021/22, respectively, as shown in Table 3. The Koftu SSI scheme's average RIS was 2.47. This result indicates that the irrigation supply from the scheme head was sufficient to meet the scheme's needs [37].

In summary, the average annual RWS and RIS values of the Koftu SSI system suggest that there is enough water to meet agricultural demands based on current cropping patterns. However, it is essential to note that the total water supply includes losses during conveyance and distribution, and the high values obtained may not necessarily mean a surplus supply at the field level in the command area, as depicted in Table 2 and Figure 1.

Table 2: Koftu Small-Scale Yearly Irrigation Water Supply and Requirement

Irrigation Years	2019/20	2020/21	2021/22
Irrigation water supply (m^3/s)	0.88	0.89	0.92
Irrigation Water Requirement (m^3/s)	0.49	0.46	0.50

Figure 1: a, b, c and d are the Samples of the Koftu Irrigation Scheme Water Delivery Division Box and Canals

The adequacy of the irrigation infrastructure to supply water in the two irrigation schemes was evaluated by assessing the water delivery capacity (WDC). This indicator determines whether the current water distribution system, comprising irrigation channels, can meet the peak irrigation demand during a particular season. A WDC value greater than 1 implies that canal capacity is not a hindrance to supplying crop water requirements [35].

In the irrigation years 2019/20, 2020/21, and 2021/22, the discharge capacity of the major canals at the system head was 0.88 m^3/s, 0.89 m^3/s, and 0.92 m^3/s, respectively. Using the CROPWAT model, the peak irrigation requirements expressed as a flow rate at the head of the irrigation systems were estimated as 0.49 m^3/s, 0.46 m^3/s, and 0.50 m^3/s for the irrigation years, respectively. The peak irrigation demand for the schemes occurred during the irrigation year 2021/22, which suggests that the current water distribution systems in the irrigation scheme were adequate and not limiting irrigation.

Table 3: Relative Water Supply and Irrigation Supply Indicators for Koftu Irrigation Schemes

	Year of Irrigation			
Performance indicator	2019/20	2020/21	2021/22	Average
Total diverted water (m3)	1017486	1019619	1064754	1033953
Total irrigated water (m3)	421110	401457	434230	418932
Relative water supply (RWS)	2.02	2.12	2.04	2.06
Relative irrigation supply (RIS)	2.42	2.54	2.45	2.47

3.2. Agricultural Output Indicators

Crop yields, area coverage, and prices were used to calculate agricultural outputs for two cultivation seasons. The output value per unit harvested area was determined by soil and crop management practices, as well as the use of agricultural technologies and irrigation water delivery infrastructure. Tables 1 and 3 show the cultivated area, area coverage, intensity, yields, and output value for each crop in the two irrigation schemes during the agricultural years 2019/20, 2020/21, and 2021/22, as well as the yield value obtained from customer interviews during data collection. Output per unit harvested area, output per unit command area, output per unit irrigation supply, and production per unit water consumption were the key performance measures used in this study [35].

The output per unit harvested area is a measure of the reaction or return of each irrigated area under current conditions. The outputs per unit harvested area for Koftu SSI programs were 11212.33 US$/ha, according to data obtained from each irrigation scheme. Table 4.18 shows the average output per unit harvested area. This statistic indicates that cropping is more intensive at the Koftu SSI Scheme, resulting in a larger yearly irrigated area in comparison to the designed command area. The outputs per unit of command area for the Koftu SSI scheme were 21094.43US$/ha, according to data obtained from each irrigation scheme and presented in Tables 1 & 3. The output per unit command area at the Koftu plan was better, according to the findings.

The output per unit irrigation water supply was calculated and returned 1.02 US$/m3 for the Koftu SSI system, as shown in Tables 1 and 3. A higher output per unit irrigation water supply indicates that a limited water resource is being well utilized. The amount of water utilized was calculated using the actual evapotranspiration from the irrigated area. For the Koftu SSI scheme, the output per unit of water consumed was 2.10 US$/m3. The output per unit of water consumed was higher depending on cropping intensity, with a higher ratio of yearly irrigated area to command area.

Table 4: Land and Water Productivity Indicators of Koftu SSI

Land and water productivity indicators	Irrigation year			
	2019/20	2020/21	2021/22	Average
OIA (US$/ha)	14209.2	10774.7	8653.1	11212.33
OCA (US$/ha)	26713.3	19610	16960	21094.43
OWC (US$/m3)	2.65	2.04	1.62	2.10
OIS (US$/m3)	1.31	0.96	0.80	1.02

Output per unit water consumed (OWC), output per unit irrigation water supply (OIS), output per unit irrigated area (OIA) and output per unit command area (OCA).

3.3. Financial Indicators

The gross return on investment (GRI) was calculated based on the actual irrigated areas of the scheme, not the projected irrigable area, and expressed in monetary values per hectare of irrigated area. The estimated cost of installing a water distribution system in both irrigation schemes was US$374,480.57 for the Koftu SSI program, as reported by the scheme's management.

In Koftu, water fees generated an average annual revenue of US$963.33. The total cost of operation and maintenance for the Koftu irrigation schemes was US$254.33 but the investment cost of the storage reservoir earthen dam water source was not factored into the calculations. This was because the goal was to compare the investment cost of water delivery structures to the overall value of irrigation season production, and the storage dam might be used for non-irrigation purposes (Molden et al., 1998). Consequently, the GRI for the Koftu SSI plan for that year was 67.07 per cent, which was higher than other rural finds. For example, studied the Batu Degaga and Doni projects and found GRIs of 13.6 per cent and 27.55 per cent, respectively [36].

However, the average financial self-sufficiency (FSS) for the Koftu SSI scheme was 378.76 per cent. This result indicates that the plan generates a satisfactory return on investment when compared to the costs of operation and maintenance. This metric demonstrates the financial strength of the schemes and the willingness of consumers to pay irrigation costs.

Nevertheless, the FSS estimated for the Koftu irrigation scheme in this study does not necessarily imply that the project is sustainable, given that the O&M expenditures reported in the records appeared to be greater than the entire scheme maintenance financial demands. Farmers in irrigation systems around the world, particularly in developing countries, generally believe that it is the responsibility of their governments to operate and maintain their irrigation schemes, and are therefore hesitant to pay irrigation fees, as illustrated in detail in Table 5 [33, 38].

Table 5: The Koftu SSI Scheme's Average Financial Indicators

Financial Indicators			
Year	Fee collected from the water users	O &M expenditures	FSS
2017/18	12000	2400	500
2018/19	12500	3750	333.3
2019/20	20000	5000	400
2020/21	40000	12000	333.3
2021/22	60000	15000	400
Average FSS	963	254	378.76

In a study of the Koftu irrigation scheme, similar financial self-sufficiency (FSS) values were observed as those found in the Great Chao Phraya Irrigation project in Thailand [39]. To increase annual operation and maintenance (O&M) expenses, Bumbudsanpharoke & Prajamwong and Masasi suggested increasing irrigation water costs paid by farmers. However, to achieve this, measures must be taken to improve farmers' willingness to pay for irrigation fees in both systems. Encouraging farmers to contribute to O&M costs without government subsidies may instill a sense of ownership, ultimately improving the operation of the two irrigation projects [33, 39].

4. Conclusions

In conclusion, the Koftu small-scale irrigation scheme in Ethiopia was found to be successful in enhancing water resource employment and improving land and water productivity. Despite not operating at its full potential, the program performed better than similar irrigation systems worldwide in terms of land productivity indicators. The water productivity outcome showed consumers' willingness to pay for irrigation costs, which contributed to the program's reasonable return on investment. The irrigation schemes were financially self-sufficient due to low operation and maintenance costs. The study highlights the usefulness of performance indicators in identifying areas for improvement in irrigation schemes. To improve the sustainability of the schemes, farmers should be encouraged to take more ownership of the projects by paying for operation and maintenance expenses without government subsidies. Overall, the study suggests that the Koftu small-scale irrigation program is a successful example of enhancing water resource employment and improving land and water productivity in Ethiopia [40-42].

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