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Assessment of irrigation water allocation, Koftu, Ethiopia

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ABSTRACT

This research investigates the fair and efficient distribution of water among irrigators, focusing on the timely and uniform delivery of water. To achieve this, the study utilized various methods such as group discussions, critical informant and expert interviews, and field flow measurements. The degree of fairness in the distribution of irrigation water was determined by analyzing the shift in the relative water supply to end users. The effectiveness of irrigation is inversely proportional to the relative irrigation supply, which can be observed in the scheme's water delivery indicators. The study found that while the estimated delivered flow of water in the head, middle, and tail reaches of the canal was 1.21, 0.58, and 0.23 m^3/s respectively, the required quantity of discharge was only 0.81, 0.31, and 0.15 m^3/s. This discrepancy resulted in the inadequate, unreliable, and unequal water supply to irrigators. The research revealed that canal operation and maintenance were the main factors limiting the system's capacity. The findings showed that the adequacy, dependability, equality, and efficiency values were 0.8, 0.14, 0.40, and 0.71, respectively, suggesting that improvements are needed to ensure the timely and equitable distribution of water to irrigators.

Key words: adequacy, dependability, equity, irrigation, water allocation

HIGHLIGHTS

- Water distribution among irrigators is the subject of research, with an emphasis on timely and uniform delivery.
- A variety of techniques, including conversations, interviews, and flow measurements, were employed to research the distribution of irrigation water.
- Irrigation efficiency is inversely correlated with relative supply, and this relationship was used to evaluate fairness by examining changes in relative water supply.
- The study found a large disparity between the estimated and required water flow, leading to an inadequate, unstable, and unequal supply for irrigators.
- Improvements are required to get around restrictions in canal operation and maintenance to offer timely and equitable water distribution, which has the potential to boost sufficiency, reliability, equality, and efficiency of the distribution system.

ABBREVIATIONS

RWS	Relative water supply
IWMI	International water management institute
WS	Water supply
O&M	Operation and Maintenance
b/n'	Between

1. INTRODUCTION

Ethiopia possesses abundant but underutilized land and water resources, despite having one of the world's largest food deficits. The government's efforts to develop these resources since the late 1980s have resulted in economic

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progress and reduced poverty levels (Haile & Kassa 2015). However, frequent droughts and climate-related hazards still leave millions of Ethiopians without food every year. Therefore, irrigation is crucial to enhance agricultural output and productivity, benefiting both rural and urban populations. The development of irrigation can also decrease the costs of food and raw materials, generate foreign income, create job opportunities, and provide a market for industrial goods. Consequently, irrigation is deemed vital for reducing poverty and ensuring food security in Ethiopia, making it a sub-sector of agriculture that manages and distributes water for irrigating crops, and is indispensable for achieving sustainable agricultural production and food security (Ermias *et al.* 2014; Ahmed 2019; Jambo *et al.* 2021).

In Ethiopia, there are three major types of irrigated agriculture patterns. The three forms of irrigation are large-scale (over 3,000 ha), medium-scale (200–3000 ha), and small-scale (less than 200 ha). Small-scale irrigation plays a dominant role in ensuring food security in Ethiopia due to landholding policies and population dynamics, as noted by Kassa & Andualem (2020) and Meja *et al.* (2020). In order to stimulate the growth of agricultural self-sufficiency, it is crucial to provide support to irrigation system users to enhance their systems and outcomes. This requires effective water distribution and allocation among customers (Hellegers & Leflaive 2015; Li & Singh 2020; Goes *et al.* 2021). Water allocation is the process of distributing available water among legal claimants based on certain rules and procedures (He & Tyner 2004; Roa-García 2014). Houessou-Dossou *et al.* (2022) stated that the reliability of water distribution systems is influenced by rainfall and flood frequency, which can also provide a solution for coping with rising water demand among users. During times of seasonal water scarcity caused by increased demand and variability in precipitation, the allocation rules and processes of water users' associations become crucial in reducing conflicts related to water.

Although efforts have been made to improve agriculture and irrigation in Ethiopia's major river basins, there is still a significant need to focus on the country's vast potential (Adgolign *et al.* 2016). The absence of a water market means that water allocation laws or processes are often not effective in ensuring the efficient distribution of irrigation water among users. Improving water use efficiency by allocating water resources more effectively is a key strategy to address water scarcity challenges in river basins, but developing nations have not achieved desired outcomes. It is essential to examine social, economic, and political aspects of water management difficulties in developing nations to find long-term solutions (Abolpour *et al.* 2007; Li & Singh 2020; Panagopoulos 2021, 2022; Panagopoulos & Giannika 2022).

The Koftu irrigation scheme, which is one of Ethiopia's small-scale irrigation systems, is hindering the region's ability to achieve sustainable agricultural production and ensure food security due to unfair irrigation water allocation among water users from upper users to end-users, Despite their usefulness, small-scale irrigation facilities still face various obstacles, as highlighted by Agide *et al.* (2016), Gebul (2021), and Nguyen *et al.* (2022). The study aims to evaluate the performance of irrigation water allocation in the Koftu irrigation scheme region of Ethiopia by assessing current practices, identifying influencing factors, evaluating effectiveness, and recommending strategies for improvement.

2. RESEARCH METHODOLOGY

2.1. Study scheme description

The Koftu-Fultino small-scale irrigation system is in the upper Awash River basin and is in the Adea district of Ethiopia's Oromia regional state. The area has a tropical environment with a varied rainfall distribution, with an average elevation of 1,920 meters above sea level. It averages 837.5 mm of rain per year and has annual minimum and maximum temperatures of 11.6 and 26.7 °C, respectively. At a wind speed of 5.1 km/h, the yearly average relative humidity is 58.6%.

At this level of analysis, more than 300 ha of land is potentially accessible for development, but due to water shortages, only 50 ha of net development was evaluated. The Oromia irrigation development authority constructed the scheme in 2013. The water is supplied by the Belbela dam outlet, which has a sophisticated diversion system. Residents of the Koftu Peasant Association are the project's beneficiaries. At least 200 families who are members of water user groups will benefit from irrigation activities as a result of this planned project.

The Belbela Earthen Dam reservoir provided irrigation water for this system. The main canal is unlined and supported by a single chute structure to handle the elevation differential between the canal and the command area. This method was used to harvest water from Division Box 1, which was 300 m away from the Belbela reservoir's main intake.

The soil at the Koftu irrigation project is black and has the texture of loam clay. The principal crops irrigated in this area are tomato, cabbage, onion, maize, potato, and pepper.

In the Koftu SSI plan, water users are organized into water user associations. Water distribution activities are organized into three categories under the control of water user groups. Irrigation water distribution was done in rotation among the three groups due to the lack of a flow metering mechanism at the farm gate, with the timing of irrigation water application regulated by crop type and plot size. Farmers could irrigate as much as they wanted until they ran out of water. Due to fluctuations in the dam's reservoir capacity for upstream and downstream farmers, the water supply in the plan varies from year to year.

2.2. Methods of data collection

Data were collected through observation, fieldwork data collecting, flow measurements, and soil characterization sample collection. During the research, current meters, staff gauges, double-ring infiltrometers, measuring tape materials, CROPWAT, CLIMWAT, Arc GIS, and GPS tools were used.

Daily discharge measurements were recorded upstream and downstream of each secondary or tertiary offtake, which was split into three categories such as head, middle, and tail reach, to arrive at the study's findings. At seven of the scheme's locations, a current meter is utilized to check the flow rate. These are the averages for three consecutive months in the year 2021: January, February, and March. CROPWAT 8.0 was used to calculate the scheme's demand.

2.2.1. Flow measurement fieldworks

The irrigation canal's true carrying capacity was determined using the current meter, with the replication of measurements taken once a week for 3 months at various locations along the canals to document temporal and geographical variations in irrigation water flows. The canal discharges were measured at 200-m intervals through secondary canals, starting at the system's intake, with 12 replications of measurements taken at each location. The discharge at the given location was computed using the area–velocity methodology and the mid-section method of discharge computation, with the replication of measurements to ensure accuracy. The diameters of canals were first measured with a tape meter, and then cross-sectional areas were calculated, with multiple replications of measurements taken to reduce measurement errors. In the research areas, the waterways are clay canals with irregular shapes, and multiple replications of measurements were taken to account for variations in shape and size. As a result, the velocity of flow through the canal was measured using a current meter. The flow velocity was calculated using the propeller rotation speed (n) obtained by the control unit at three segments of canal flow width. The mean flow velocity was calculated using the average number of rotation speeds (Figure 1).

Flow depth was measured through canals at specific locations, and flow rotations were recorded using a current meter and stopwatch. Following that, the actual discharge of each segment was calculated by multiplying the segment's average area by the velocity of flow. Lastly, the average real carrying capacity of the canal was calculated by aggregating the average discharge for each segment.

2.2.2. Soil infiltration rate and texture

Soil samples were taken from agricultural plots (head, middle, and tail) at various depths up to 90 cm to assess soil physical properties (textures, field capacity (FC), permanent wilting point (PWP), and total available moisture contents). The USDA soil texture triangle uses textural grades and mass ratios or percent by weight evaluated in a laboratory to determine soil texture (USDA 2008). A double-ring infiltrometer was utilized in the field to assess the infiltration rate of the soil, as illustrated in Figure 2. On several plots, measurements were taken. A double-ring infiltrometer with 30 and 60 cm diameters was implanted by hammering both rings into the root zone. A stopwatch can also be used to keep the track of time. Throughout the recording process, water levels in the inner ring were continuously monitored until the soil's fundamental infiltration rate was met.

2.2.2.1. Infiltration rate of soil. The rate at which water drains into the soil is known as the infiltration rate. In millimeters, the depth of water that can permeate the soil in 1 h can be measured. Averaging the recorded experimental data yielded 6.8 mm/h as the average basic infiltration rate for the studied region. The findings of the soil laboratory revealed that clay is the predominant soil texture in both research locations. A clay soil texture, as illustrated in Table 1, has a basic infiltration rate of 1–7 mm/h. According to FAO (2002), it is

Figure 1 | Measuring canal depth, width, and flow of water.

Figure 2 | Observation of the study area soil infiltration rate.

characterized as soil with a low infiltration rate, which is a characteristic of clay-textured soil. As a result, the FAO's proposed soil infiltration rate field results were within the experimental soil infiltration rate field results (Figure 3).

2.2.2.2. Soil texture. In irrigated agriculture, identifying soil colors, texture, structure, depth, and chemical properties is crucial. The soil in the study region of the irrigation plant is black and has a loam-clay texture. It is sticky when moist and cracks when dry. Such soils have a high-water retention capacity and a low

Table 1 | Soil particle distribution and textural class in the Koftu-Fultino scheme

Particle size distribution				
Soil depth (cm)	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Class**
0–30	51.07	16.67	32.27	Clay
30–60	43.40	22.67	33.93	Clay
60–90	46.40	20.67	36.27	Clay
Average	46.96	20.00	34.16	Clay

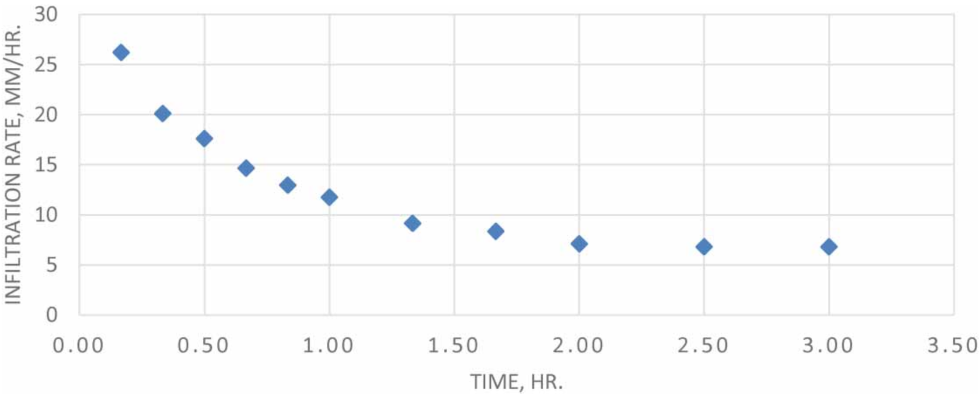

Figure 3 | Distribution of the study area infiltration rate.

infiltration rate among other physical features. Table 1 shows that clay is the most common soil texture in the irrigated area.

Table 2 provides information on the FC, PWP, and total available water content (TAWC) values of the soil. For soils with more than 45% clay content, a differential of 1.47 g/cm^3 is recommended between the water content of the soil at FC and the PWP, which can restrict root growth due to high bulk densities (MPCA 2021). The average TAWC in the Koftu-Fultino small-scale irrigation system was 214.47 mm/m, which is consistent with the FAO Water Quality for Agriculture Literature value (Ayers & Westcot 1985).

Table 2 | Soil FC, PWP, and TAM of the Koftu-Fultino SSI scheme

	Parameters		
Soil depth (cm)	**FC (%)**	**PWP (%)**	**TAM (mm/m)**
0–30	41.71	26.93	217.27
30–60	40.85	26.10	216.83
60–90	40.79	26.57	209.03
Average	41.12	26.53	214.47

Soil texture and structure have a significant impact on water-holding capacity, which can affect agricultural water output in irrigation schemes. To improve soil structures in the irrigation scheme, appropriate organic matter addition, tillage, soil conservation, crop management, cropping practices, and rotations are essential.

2.3. Analyzing data

2.3.1. Evapotranspiration as a reference (ETo)

Rainfall data were created using meteorological data and CLIMWAT 2.0 from a neighboring Bishoftu station with the same Argo condition as the study area because the study location lacked a meteorological station. As a result, whereas the average total annual effective rainfall in the research region was found to be 651.2 mm, the average annual total rainfall was found to be 837.5 mm. June through September are the wettest months of the year. Over the entire year, the reference evapotranspiration is constantly high (Figure 4). The region is regarded as a moisture-stressed area; thus, irrigation is required to maintain agricultural production.

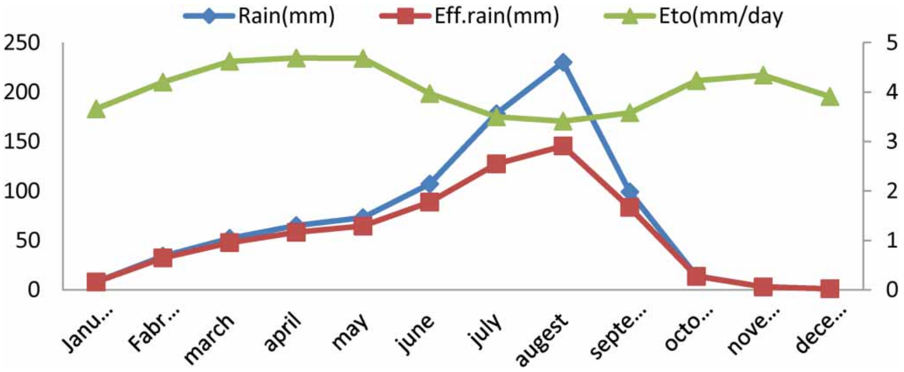

Figure 4 | Study area rainfall, effective rainfall, and Eto.

The CROPWAT 8.0 computer application was used to assess the overall water requirements of important crops grown in the research locations. The model requires climate data such as minimum and maximum temperatures, wind speed, relative humidity, and daylight hours. The crop evapotranspiration (ETc) and irrigation water requirement (IWR) were then determined using formulae (1 and 2).

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc} \tag{1}$$

$$\mathrm{IWR} = \mathrm{ETc} \ - \mathrm{RFeff} \tag{2}$$

where Kc is the cropping coefficient and RFeff is the effective rainfall.

The simplest sets of similar performance indicators published by IWMI (Molden *et al.* 1998) were utilized for the same cropping season for the full blocks. As a result, the selected blocks were compared using only the most basic sets of comparison and process indicators. The following irrigation water delivery or water use metrics were used to assess the performance of scheme's water delivery. The main purpose of the water supply performance review was to figure out if the water provided was adequate. In this study, the following metrics were utilized to evaluate the performance of water delivery:

$$\text{Efficiency (PF)} = \frac{1}{T}\sum_{T}\left(\frac{1}{R}\sum_{R}\frac{\mathrm{QD}}{\mathrm{QR}}\right) \tag{3}$$

$$\text{Adequacy (PA)} \ = \ \frac{1}{T}\sum_{T}\left(\frac{1}{T}\ \sum_{R}\frac{\mathrm{QD}}{\mathrm{QR}}\right) \tag{4}$$

$$\text{Equity (PE)} = \ \frac{1}{T}\sum_{T}\mathrm{CvR}\left(\frac{\mathrm{QD}}{\mathrm{QR}}\right) \tag{5}$$

$$\text{Dependability (PD)} = \frac{1}{R}\sum_{R}\mathrm{CvT}\left(\frac{\mathrm{QD}}{\mathrm{QR}}\right) \tag{6}$$

where CvR QD/QR means the spatial coefficient of variation (the ratio of standard deviation to mean) of the ratio, QD/QR (relative water delivery) at delivery points over the hydraulic level or reaches R, QD is the actual volume of water provided, QR is the required amount of water, R is the region served by the system, and T is the period (irrigation season).

When the dependability and equity values were close to or equal to zero, water distribution was consistent from the canal and month to month. (Water given/water requested) is the temporal coefficient of variation of water supplied/water sought across time (T). Similarly, over the region, the geographical coefficient of variation of water delivered/water sought is (water delivered/water requested) (*R*). When calculating water delivered/water requested or water requested/water delivered, we assume that the ratio is one if the denominator is zero.

In general, the terms adequacy, efficiency, dependability, and equity refer to the relationship between the actual water supply and the crop water demand as a comprehensive assessment of irrigation scheme performance. The standard for evaluating performance indicators was developed by Fan *et al.* (2018). According to the evaluation standard in Table 3, the performance can be rated as good, fair, or poor.

Table 3 | Evaluation standard for performance indicators

	Performance classes		
Performance indicators	**Good**	**Fair**	**Poor**
PA – Adequacy	$0.90 \leq \text{PA} \leq 1.0$	$0.80 \leq \text{PA} < 0.90$	$\text{PA} < 0.80$
PD – Dependability	$0.0 \leq \text{PD} \leq 0.10$	$0.10 < \text{PD R} \leq 0.25$	$\text{PD} > 0.25$
PE – Equity	$0.0 \leq \text{PE E} \leq 0.10$	$0.10 < \text{PE E} \leq 0.20$	$\text{PE} > 0.20$
PF – Efficiency	$0.85 \leq \text{PF Ef} \leq 1.0$	$0.70 \leq \text{PF} < 0.85$	$\text{PF} < 0.70$

According to the equation, the control area's calculation units (time and space) as well as the unit of space had an impact on the outcomes of the performance indicators (3–6). As a result, in this study, the month and the secondary canal control area were chosen as time and space units, respectively. As a result, the performance of water allocation under this irrigation plan is mostly affected by the level of cultivation by farmers. Similarly, the irrigation scheme's ability to distribute water is represented when water distribution performance is evaluated in terms of adequacy, efficiency, dependability, and equity. These indicators can accurately depict if the physical system and operational canal decision can deliver the scheduled water to the field. In addition, the irrigation system must adhere to a set of requirements.

3. RESULT AND DISCUSSION

3.1. Estimation of the irrigation water delivery and demand for water allocation

The allocation of irrigation water was visible in the scheme's water delivery indicators, which were assessed in the canal for adequacy, equality, reliability, and efficiency. The change in the relative water supply of end-users determines the degree of equality or imbalance. The inverse of relative irrigation supply is overall irrigation efficiency. According to the conclusions of this inquiry, Koftu-Fultino's overall performance was typical. Water allocation contributed more to the irrigation scheme's poor performance than the water supply according to the analysis of irrigation water allocation performance.

3.1.1. Flow requirement determination

The canal's required quantity of discharge (QR) was calculated both temporally and spatially. Table 4 shows the projected values for the needed discharge. Throughout the year, the geographical average necessary discharge levels for the seven fields were 0.42 m^3/s. The flow required for the cropped length at various locations, as well as the flow required by all offtakes, varied from 0.31 to 1.18 m^3/s month to month. SC-2 received the lowest score, while head received the best (offtake). The differences in crop water requirements in the head, middle, and tail reaches are depicted in this diagram. The required discharge for the head, middle, and tail reaches was 0.81, 0.31, and 0.15 m^3/s, respectively. The head reach offtakes required a lot of water, whereas the middle reach offtakes required less. This could be because each offtake covers a distinct geographical area. On average, the required discharge value in the research zone was 0.42 m^3/s. A similar finding was discovered by Awulachew & Ayana (2011) and Efriem & Mekonen (2017).

3.1.2. Determination of delivered flow

The given result discusses the estimation of delivered flow (QD) at selected locations over a study period, which represents the spatially averaged values of the supplied flow over time. The study period includes January, February, and March, and the expected delivered flow values for these months are 4.24, 2.59, and 3.54 m^3/s, respectively. It is noted that the lowest delivered flow value was observed in February, and the highest was in January.

Table 4 | Average required (QR) and delivered (QD) discharge on the primary canal (m^3/s)

Reach location	Months	January		February		March		Temporal mean QR (m^3/s)	Temporal mean QD (m^3/s)	Standard deviation
		QR	**QD**	**QR**	**QD**	**QR**	**QD**			
Head	Offtake	1.18	1.89	1.18	1.28	1.18	1.58	1.18	1.58	0.29
	SC2-1	0.43	1.07	0.43	0.63	0.43	0.78	0.43	0.83	0.25
	Mean	0.81	1.48	0.81	0.96	0.81	1.18	0.81	1.21	0.26
	St. Dev.	0.53	0.58	0.53	0.46	0.53	0.57	0.53	0.53	0.04
Middle	SC2-2	0.31	0.70	0.31	0.37	0.31	0.67	0.31	0.58	0.18
	Mean	0.31	0.70	0.31	0.37	0.31	0.67	0.31	0.58	0.18
Tail	TC2-3 and 1-2	0.19	0.43	0.19	0.20	0.19	0.36	0.19	0.33	0.10
	SC2-3	0.10	0.15	0.10	0.11	0.10	0.15	0.10	0.14	0.02
	Mean	0.15	0.29	0.15	0.16	0.15	0.26	0.15	0.23	0.06
	St. Dev.	0.06	0.20	0.06	0.06	0.06	0.15	0.06	0.13	0.06
Spatial mean		0.42	0.82	0.42	0.49	0.42	0.70	0.42	0.67	0.16

The supplied discharge varied at different points in time due to temporal variance in the delivered flow. The supplied discharge ranged from 0.14 to 1.58 m^3/s, with SC2-2 having the lowest value and the offtake having the highest value. SC2-2 irrigated a larger area, and therefore, the supply flow to the tertiary offtake was also larger. To meet the demand of the broad geographical area supplied by this offtake, it was necessary to increase discharge throughout the year.

Table 4 shows the reach-by-reach variance in time-averaged delivered flow values. The head, middle, and tail reaches had an average delivered flow of 1.21, 0.58, and 0.23 m^3/s, respectively. The standard deviation flow of the scheme became less from the head to the tail of the command area.

In summary, the given result describes the estimation of delivered flow at selected locations over a study period, and it highlights the temporal and spatial variability in the supplied flow. It also discusses the variation in the supplied discharge and the impact of the geographical area on flow distribution. Additionally, it shows the variation in the delivered flow along the command area's different reaches and the decreasing standard deviation of flow from the head to the tail of the command area.

3.2. Irrigation water delivery indicators

3.2.1. Adequacy indicator (P_A)

According to the given result, the irrigation water supply in the Koftu-Fultino Irrigation Water Development's head, middle, and tail reaches is acceptable due to the application and delivery activities. This puts the scheme's performance in the fair range, as shown in Table 5. During the study period, enough water was available at the scheme source.

Table 5 | Water distribution adequacy on the system on average

Month	Head		Middle	Tail		Spatial average (PA)	Standard deviation
	Offtake	**SC2-1**	**SC2-2**	**TC2-3-1 and 2**	**SC2-3**		
January	0.89	0.85	0.56	0.85	0.90	0.81	0.14
February	0.90	0.84	0.65	0.84	0.86	0.82	0.10
March	0.70	0.86	0.70	0.81	0.87	0.79	0.08
Average (temporal)	0.83	0.85	0.64	0.83	0.88	0.80	0.10
Average reach (P_A)	0.84		0.64	0.85			0.12
St. Dev	0.11	0.01	0.07	0.02	0.02	0.02	0.03

However, there is still a shortage of water supply in the system, as evidenced by the excess calculated to be 0.84 at the head and the P_A (performance assessment) ratio of 0.80, indicating that the supply falls short of the demand. The demand-to-supply ratio is 1.00, indicating that less water is provided than required. A P_A ratio of

1.00 or close to 1.00 indicates adequate water supply, while a P_A ratio of 0.80 or less indicates insufficient water supply.

The temporal value of adequacy at the system's head, middle, and tail is 0.80, indicating fair performance. However, it should be noted that the distribution of water supply is decreasing from upper users to downstream areas. Similar values of 0.84, 0.63, and 0.85 for the head, middle, and tail reaches, respectively, were reported (Efriem & Mekonen 2017).

In summary, the given result suggests that the irrigation water supply in the Koftu-Fultino Irrigation Water Development is acceptable, but there is still a shortage of water supply in the system. The PA ratio indicates that the supply falls short of the demand, but the temporal value of adequacy suggests fair performance. It is also noted that the distribution of water supply is decreasing from upper to downstream areas.

3.2.2. Equity (P_E)

The given result in Table 6 suggests that the average monthly equity of water distribution in the Koftu-Fultino Field irrigation system was 0.40, which is considered poor performance according to the statistics summarized. This indicates that the distribution of water among different users within the irrigation system is not equitable, and some users may be receiving less water than others.

Table 6 | Average dependability of water supplied and equity of water distribution on the system

	Head		**Middle**	**Tail**				
Month	**Offtake**	**SC2-1**	**SC2-2**	**TC2-3-1 and 2**	**SC2-3**	**Spatial average**	**St. Dev.**	**CVR (P_E)**
January	1.10	3.20	2.10	2.65	1.55	2.12	0.84	0.396
February	1.12	2.12	3.12	2.80	1.12	2.06	0.93	0.451
March	1.09	2.58	2.60	2.65	1.55	2.09	0.725	0.346
Average (temporal)	1.10	2.63	2.61	2.70	1.41	2.06	0.40	
Average reach	1.864		2.61	2.055		2.15		
St. Dev.	0.015	0.542	0.51	0.087	0.25	0.03		
CV_T (P_D)	0.01	0.29	0.19	0.042	0.12	0.14		
Average CV_T (P_D)		0.15	0.19	0.08				

Additionally, an important finding of the study is the lack of cross regulators and water quality monitoring gauges in the system to monitor siltation accumulation in the canal system. This means that there is a potential for siltation to accumulate in the canals, which could reduce the flow of water and cause further inequities in water distribution among different users.

The study also notes that comparable values were determined by Alemayehu (2018). This suggests that the problem of poor equity in water distribution and the lack of proper monitoring measures to address siltation accumulation in the canal system may have persisted over time.

In conclusion, the given result highlights the poor performance of the Koftu-Fultino Field irrigation system in terms of equitable water distribution, as well as the need for proper monitoring measures to address potential issues such as siltation accumulation in the canal system.

3.2.3. Dependability (P_D)

The result being discussed is the dependability of the Koftu-Fultino irrigation scheme, which refers to the reliability of the system to deliver water to its users when needed. The study found that the dependability of the irrigation scheme was mostly adequate, with average dependability values at system's head, middle, and tail reaches being 0.15, 0.19, and 0.08, respectively, and an overall average dependability of 0.14.

This result indicates that the irrigation water users (IWUs) in the Koftu-Fultino scheme were committed to sharing irrigation water, and the water committee responsible for managing the scheme communicated effectively. These factors likely contributed to the scheme's overall dependability.

The study also notes that farmers may prefer an irrigation system with a limited but consistent water supply over one with a variable supply. This is because a consistent supply allows farmers to plan their activities more effectively, leading to higher crop yields. The result is in line with previous studies conducted by Efriem

& Mekonen (2017) and Alemayehu (2018), which also found the Koftu-Fultino irrigation scheme to be dependable.

Overall, the result suggests that the Koftu-Fultino irrigation scheme is well managed, and its users are committed to sharing water, which has resulted in a dependable water supply. This information can be useful for policymakers and irrigation managers in other regions who want to learn from successful irrigation schemes and improve the dependability of their systems. Furthermore, farmers may prefer a consistent but limited supply of water over a variable but plentiful supply. This preference is because farmers can plan their activities more effectively if they know that water deliveries will be made on time, which can result in higher agricultural output (Gorantiwar & Smout 2005).

3.2.4. Efficiency (P_F)

The result describes the irrigation efficiency of the Koftu-Fultino irrigation scheme, both in terms of temporal and spatial irrigation effectiveness. The values are presented in Table 7, which shows the average values over time and space.

Table 7 | Average spatial and temporal irrigation efficiency

	Head		**Middle**	**Tail**			
Month	**Offtake**	**SC2-1**	**SC2-2**	**TC2-3-1 and 2**	**SC2-3**	**Spatial average PF**	**Standard deviation**
January	0.62	0.56	0.69	0.82	0.70	0.68	0.10
February	0.60	0.66	0.68	0.76	0.88	0.72	0.11
March	0.61	0.68	0.71	0.80	0.89	0.74	0.11
Average P_F	0.61	0.63	0.69	0.79	0.82	0.71	0.09
Temporal average P_F	0.62		0.69	0.81			0.10
St. Dev.	0.01	0.06	0.02	0.03	0.11	0.03	0.01

Regarding temporal irrigation efficiency, the results suggest that the irrigation system's head had good irrigation efficiency throughout the year. This is attributed to the unrestricted water supply in the first, second, and third branch canals. In other words, there was an adequate amount of water supply to meet the irrigation needs of the head area, resulting in good irrigation efficiency.

Concerning spatial irrigation effectiveness, the study found that the Koftu-Fultino irrigation system had an average efficiency of 0.71, which is considered adequate. This means that 71% of the water delivered to the irrigation system was effectively utilized by the crops. These findings are consistent with other studies conducted by Dejen (2015) and Efriem & Mekonen (2017), which also reported similar values for spatial irrigation effectiveness.

In conclusion, the paragraph suggests that the Koftu-Fultino irrigation scheme had good temporal irrigation efficiency at the head area throughout the year and adequate spatial irrigation effectiveness. These findings are important as they provide insights into the performance of the irrigation system and can inform future improvements to enhance irrigation efficiency.

3.3. Summary of the water delivery indicators

Table 8 presents the water delivery parameters for the Koftu-Fultino irrigation scheme over 3 months, with the equity rating found to be 'poor.' This suggests that water was not distributed evenly to end-users. However, the adequacy of water distribution and dependability of water delivery was rated as 'fair.' The overall efficiency of the system was also rated as 'fair,' indicating that improvements are needed to enhance its efficiency. Although the delivered water demonstrated good delivery performance, more work is needed to improve water allocation and overall effectiveness. To improve the system, modern field-monitoring equipment and technology should be utilized, along with guidelines for farmers' water orders under varying climatic conditions. Communication between irrigation scheme administrators and farmers must also be strengthened, particularly during peak water demand seasons. The fairness of performance is influenced by several factors, but inefficient operation and maintenance were identified as the cause of the canal system's siltation.

Table 8 | The overall evaluation of water delivery indicators

	Koftu-Fultino SIS	
Water delivery indicators	**Scale value**	**Status**
P_A	0.80	Fair
P_F	0.71	Fair
P_D	0.14	Fair
P_E	0.40	Poor

4. CONCLUSION

The primary objective of this investigation was to evaluate the performance of the Koftu-Fultino irrigation system by examining diverse water supply and delivery parameters, including sufficiency, efficiency, dependability, and equity, as well as the spatial and temporal distributions of water supplied to secondary canals. The outcomes indicated that the sufficiency, dependability, equity, and efficiency values were 0.8, 0.14, 0.40, and 0.71, respectively. The water delivery performance of the irrigation system was rated as satisfactory in terms of adequacy, efficiency, and dependability, but unsatisfactory in terms of equity, which was caused by the imbalance of water supply to end-users. The delivered water flow exceeded the necessary discharge rate, suggesting insufficient and inefficient irrigation water delivery to the canals. Additionally, the delivery of irrigation water to each farmer's plot was frequently inefficient, leading to reduced system performance and difficulty in fulfilling crop water demands. It is critical to assess performance indicators based on water allocation and delivery to identify areas that require improvement. Users must also effectively mobilize themselves to manage the system. This research provides valuable insights for stakeholders and researchers interested in the study area, as well as encourages the use of advanced field-monitoring equipment and technology and serves as a guide to determine farmers' water requirements in various climatic conditions.

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AUTHOR CONTRIBUTIONS

Author contributions for this work were as follows: D.B.H. conceptualized the study, curated the data, prepared the original draft, and created visualizations. M.A.G. provided supervision and validated the software. J.A.Du.P. reviewed and checked the grammar of the manuscript, while W.O.E. reviewed and edited it. All authors have read and approved the final version of the manuscript for publication.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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