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Research Article

Assessing the Performance of Conveyance System of Jato Small-Scale Irrigation Scheme of Wayu-Tuka District, East Wallaga Zone, Oromia, Ethiopa

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Abstract

The performance assessment of a small-scale irrigation project plays a vital role in evaluating its effectiveness and addressing potential shortcomings in achieving desired outcomes. This study aims to provide a comprehensive analysis of the Jato small-scale irrigation project, assessing its performance based on various criteria and indicators. The study evaluates the project's infrastructure maintenance and system efficiency. The designed command area of the scheme is seventy-five (75 ha) but the current irrigated area of the scheme is sixty (60ha) only. To achieve the objectives, primary and secondary data were collected. To gather both primary and secondary data, data-gathering techniques include surveys, interviews, field observations, and meteorological data. Before, during, and after an irrigation event, while farmers were carrying out their regular irrigation practices, several field characteristics were measured and/or observed. These data included the type of crop, irrigation water discharge in the canal, and field size. A survey concerning the availability of water was also carried out among farmers. CROPWAT 8.0 Software was used to organize the crop pattern of the study area along with other relevant data, including soil, climate, rain crop, and crop pattern. Water flow measurement results of the Jato small-scale irrigation scheme at the head, middle, and tail of the lined & unlined main canal were found to be 53.6l/s, 45.4 l/s, and 29.9l/s respectively. The average water flow measurement result of the scheme is 43l/s which reduced from required flow by 18.15l/s. From the analyses of the water balance indicators, the canal conveyance efficiency, canal conveyance loss, application efficiency, and overall efficiency were found to be 70%, 30%, 70%, and 50% respectively. The overall average main canal conveyance efficiency and water conveyance loss were below the recommended values. The studies have shown that the effective infrastructure, irrigation ratio, and water surface elevation ratio of the scheme were found to be 66.7%, 80%, and 66% respectively. However, there were certain areas for improvement identified, such as the need for better coordination among project stakeholders and enhanced maintenance practices to ensure the long-term functionality of irrigation infrastructure.

Keywords

Conveyance Efficiency, Conveyance Loss, Crop water requirement, Irrigation Systems, Jato SSI Scheme, Maintenance Indicators

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1. Introduction

Water consumption rises everywhere by the global population. Agriculture is the sector that uses the most water worldwide. Irrigation plays a principal position in sustainable improvement and poverty reduction [1, 2]. Irrigation water can be received from a river or pumped [3].

Ethiopia is endowed with a substantial amount of water sources that receive about 980 billion cubic meters of rainwater per year [4]. One manner to reinforce agricultural output and fulfill Ethiopia's expanding need is through irrigation [5].

In Ethiopia, irrigation is seen as a fundamental technique for reducing poverty, reaching food security, and improving the economics of the farming network by producing additional cash during the dry season. Ethiopia has a total potential arable land of approximately 74 million hectares [6]. The total agricultural land area in Ethiopia was approximately 74.3 million hectares; out of which only 2.7 million hectares were irrigated [7]. However, to achieve this lofty goal, Ethiopia must overcome the following four significant institutional, socioeconomic, technical, and environmental challenges [7].

The poor performance of the current irrigation systems is one of the obstacles to the growth of irrigation [8]. Underperformance affects all scheme sizes (small, medium, and large) throughout Ethiopia [9]. This study examined the operation of irrigated systems in the Jato irrigation project with the overall goal of evaluating system performance and suggesting workable solutions for enhancing planning and implementation performance, which will in turn improve the performance of small-scale irrigation schemes managed by the community.

2. Materials and Methods

2.1. Location and Description of the Study Area

The Jato small-scale irrigation scheme is situated in the Boneya Molo peasant association's East Wallaga Zone Wayu Tuka District of Oromia Regional State. The project's command area is about 10.1 km away from the woreda capital, Gute town. The command area of the project is estimated to be about 60 ha and is planned to be irrigated through diversion from the River. The scheme head work is located at 8^0 52’30’’N - 8^0 59’30’’N, Easting 36^0 42’30’’E -36^0 56’30’’E, and an altitude of 1724m.a.s.l.

In the Oromia National Regional State's East Wallaga Zone, the Wayu Tuka District is situated roughly 322 kilometers to the west of Addis Ababa. The road from the site to Gute town is a weather road and from Nekemte town to Gute town Asphalt road is 12 km.

The boundaries of Wayu Tuka District are Wamahagalo in the north, Sibu Sire in the east, Leka Dulacha in the south, and Guto Gida in the west. The Woreda consists of 12 Kebeles, 10 rural, and 2 urban centers, covering a total area of 28,952.795 Ha. The district has an estimated 40,427 hectares of rural land covered by different crops and natural forests. Stream Jato flows from north to south, spanning the main Addis Ababa asphalt road to Nekemte.

The Jato irrigation project was established by the regional government. The project was constructed in 1994 E.C. for the 75 ha of command area but the current irrigated area was 60 ha which gives a direct benefit for 157 householders directly.

The project has served for 14 (fourteen) years without any major maintenance and rehabilitation even though minor maintenance has taken place at the farmer's level which actively participated in both the maintenance and operation phases. This scheme's main canal is 2.535 kilometers long, with some parts of the canal unlined. Both lined and unlined canal systems exist. Water was intended to be transported to the field by a lined canal with a 0.4 m width and 0.5 m depth. The design discharge inflow to the main canal is 52.15l/s. The soil of the study area is medium (loam). The location of this study area is shown in Figure 1.

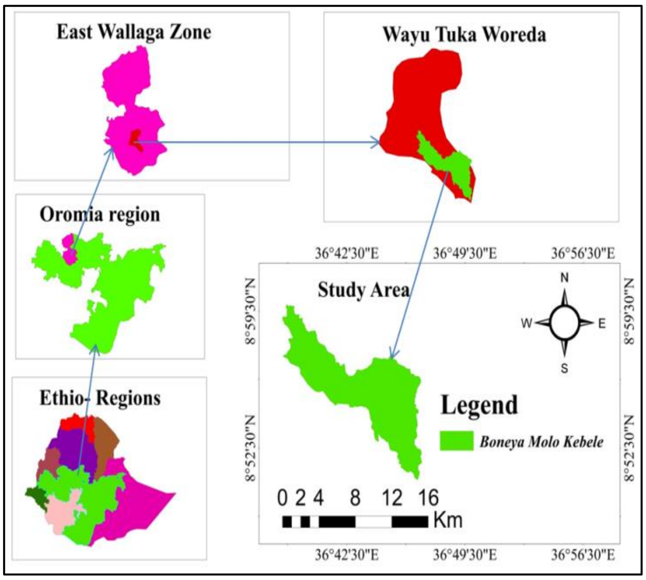

Figure 1. Location map of the study area.

2.2. Materials and Tools Used in the Study

2.2.1. Materials

1) Digital camera
2) Measuring tape
3) GPS
4) Stopwatch

2.2.2. Tools

1) ArcGIS10.8
2) CROPWAT8.0 Software

3) Microsoft Excel (spreadsheet)

2.3. Diversion Headwork Structures

The weir structure was constructed with financial support from the regional government and became functional in 1994. The designed and actual command areas in irrigation were 75 and 60 ha respectively. It was intended to serve around 157 households found in Boneya Molo Kebele. The conveyance system of the irrigation scheme consists of a Main canal (MC) taking water from the corresponding intake of the weir [10–12]. The main canal starts from the water abstraction site on the side of the weir and conveys water for a length of 2535 m of the main canal, for the first 2500 m it is a lined canal and for the rest, it is an unlined canal. So for evaluating the conveyance efficiency of the main canal flow measurements were taken on 3 sections of the canal (head, middle, & tail of canal). A type of weir is a Broad crested masonry weir. The Length or span of the weir overflow was taken 20m from the existing situation of the river section.

Figure 2. *Jato SSIP weir view from the downstream.*

2.4. Cropping Pattern

Different annual crops are produced by beneficiaries around the project area. The major ones are; Pepper, Potato, Tomato, Wheat, etc. Almost all cereal crops in the area are produced by rain-fed agriculture and small parts of vegetables are produced by wetlands and traditional irrigation.

Table 1. *Crop-type area coverage.*

S.No.	Crop type	Coverage (ha)	% of coverage
1	Potato	21	35
2	Tomato	9	15
3	Pepper	7.2	12
4	Wheat	22.8	38
Total		60	100

The yield potential of these annual crops is a function of environmental conditions, such as the availability and prevalence of rain. All cereal crops are produced by local seeds and the yield per hectare gained is low. Because, of the shortage of availability of improved varieties of seeds and inputs.

Figure 3. *Wheat crop grow in the command area.*

2.5. Method of Data Collection

2.5.1. Primary Data Collection

(i). Frequent Field Observations

It was conducted to observe and investigate the method of water applications, and practices related to water management techniques, the water delivery structures status, and channels status in the whole scheme. Every structure constructed in the scheme was visited and its status was to see the number of ones that are functioning adequately and the ones that are not functioning adequately.

(ii). Measurements of Water Flow at the Main Canal

Using the floating method, the Jato irrigation canal flow was measured. At specified points, the main canal discharges were measured. Based on this average discharge coupled with the total flow time, the total volume of water diverted by the irrigation scheme was estimated. The calculation of discharge using the floating method involves the following steps:

1. Measure the distance between two known points along the canal or channel
2. Place the float at the starting point and start a stopwatch.
3. Record the time it takes for the float to reach the ending point
4. Calculate the velocity by dividing the measured distance by the recorded time
5. Lastly, determine the discharge by multiplying the velocity by the pipe or channel's cross-sectional area. Measurements can be made at the same location by dividing the cross-section into three sections at the middle, left, and right ends of the canal. The average depth can be calculated by dividing the total number of measurements by the total number of measured depths.

$$D_{ave} = \frac{d1+d2+d3}{3} \quad (1)$$

Where: D_{ave}- average water depth (m),
d1- left end water depth (m),
d2- mid-water depth (m), and
d3- right end water depth (m)

The main canal in the study area is a 0.4 m wide rectangular lined canal. The average width and average depth of the canal have been multiplied to determine the cross-sectional area. It was advised that this be done by first adding up all of the partitions that had been separated into depth measurements at specific intervals and then multiplying the result by the average depth.

$$A = D_{ave} * W_{ave} \quad (2)$$

Where: W_{ave}: the canal's average width (m), and $D_{ave:}$ average depth (m) is given.

The flow velocity was assessed by choosing a section of the canal that was 15 meters long the canal and straight, placing two stakes, positioning a floating object on the center line of the canal at least 5 meters upstream of point 1, starting the stopwatch when the object reaches point 1, recording the time the floating materials take to reach point 2, and repeating the previous steps three times to calculate the average.

$$t_{ave} = \frac{t1+t2+t3}{3} \quad (3)$$

Where t1, t2, and t3, respectively, are the first, second, and third trials time taken for the floating object to travel a known distance (seconds), and t_{ave} is the average time. This is how the surface velocity was determined:

$$V_{sur} = \frac{Dt}{Tt} \quad (4)$$

Where D_t is distance travel in meters, T_t is time travel, and V_{sur} is the channel's surface velocity in (m/s).

The mean velocity is calculated using a correction factor from the surface velocity measured by this method.

To determine the mean velocity of flow on the Jato small-scale irrigation scheme, a correction factor was applied.

$$V\ mean = K * V_{su} \quad (5)$$

Since the measurement was taken at the surface due to the external factors that affect the tennis ball like wind and wave action, a correction factor (K) of 0.85 was taken for safety factors [10].

The cross-sectional area of the flow perpendicular to the direction of flow is multiplied by the average water velocity to estimate the flow rate.

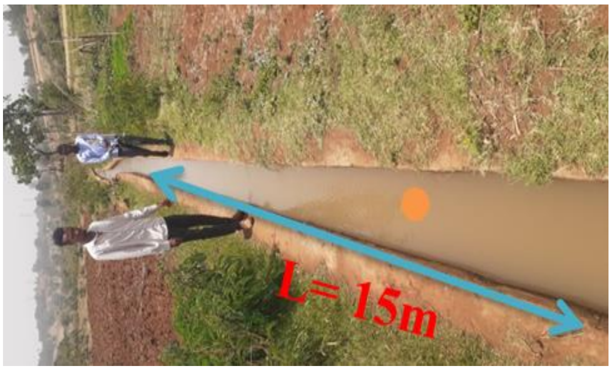

Figure 4. *Flow measurement by floating method.*

Thus, discharge can be calculated by the area-velocity method based on [10].

$$Q = 0.85 * A * V_{mean} \quad (6)$$

Where Q is the discharge rate in cubic meters per second (m^3/sec), A is the cross-sectional area of the channel square meter (m^2) and V is the velocity of the floating object meters per second (m/sec).

2.5.2. Secondary Data Collection

Secondary data collection was carried out by visiting different related government sectors. This information includes the irrigated area, meteorological data, Soil data to calculate crop water requirement, irrigation requirement, and different crop data from the agricultural office and other necessary materials.

2.6. Data Analysis Techniques

The data were collected from both primary and secondary sources. Meteorological data and Soil data were analyzed using Cropwat8.0 software, and Microsoft Excel (spreadsheet). The results are presented in the table and graph formats. Data collected from interviews and field observations were qualitatively assessed.

2.7. Determination of Effective Rainfall

In the past, different methods were proposed for effective rainfall estimation and these methods are direct measurement method, empirical method, or soil water balance methods; and the best result is obtained by soil water balance methods. These methods include a fixed percentage of rainfall, dependable rainfall, empirical formula, and the USDA Soil Conservation Service Method [11].

Effective rainfall can be calculated using the following formulae.

$$P_{eff} = \frac{P_{mon}(125 - 0.2 * P_{mon})}{125}, \text{ for Pmon} \leq 250 \text{ mm} \quad (7)$$

$$P_{eff} = 125 + 0.1 * \text{Pmon, for Pmon} > 250 \text{ mm} \quad (8)$$

When Rain (mm) & Eff rain (mm)

2.8. Determination of CWR and IWR

The CROPWAT8.0 was used to calculate the crop water requirement (CWR) and irrigation water requirement (IWR) of the irrigated crops at the field level and the irrigation scheme as a whole. By using the Penman-Monteith method to calculate reference evapotranspiration, this model may determine how much water is needed for crops [11]. The model needs climatic information, such as the mean monthly precipitation, minimum and maximum temperature (^{o}c), relative humidity (%), wind speed (km/day), and sunshine hours (hr), to calculate the reference evapotranspiration (ETO) value. After estimating effective rainfall using the USDA Soil Conservation Service (SCS) method, the determination of IWR was carried out [12].

$$\text{ETcr} = \text{ETo x Kc} \quad (9)$$

However, ETcr = is crop water need

ETo = Reference crop evapotranspiration in millimeters per day, and Kc = Crop coefficient

2.9. Determination Internal Performance Indicators

2.9.1. Canal Conveyance Efficiency

Canal conveyance efficiency (Ec) is the ratio in percent of the amount of water delivered by a channel or pipeline to the amount of water delivered to the conveyance system [10], [13]. Ec was computed using the following formula.

$$\text{Ec} = \frac{Q_0}{Q_i} * 100\%. \quad (10)$$

Where Ec is conveyance efficiency (%); Qo = quantity of water delivered by a conveyance system (outlet); and

Qi = quantity of water delivered to a conveyance system (inflow).

If conveyance efficiency is greater than one (Ec >1 implies more water leaves a specific canal section than that which enters it, while if equal to one (Ec=1) implies there is no water loss over the section under consideration. If conveyance efficiency is less than one (Ec < 1) indicates that there was water loss in the section and therefore a need for maintenance of the system [14].

2.9.2. Canal Conveyance loss

It measures the efficiency of the canal system during conveying water by losing water over a given travel distance. A water conveyance loss ratio can be calculated for each section of the main & secondary canal as recommended by [10]. Therefore, the Lc is calculated as;

$$\text{Lc} = \frac{(Qi - Q_0)}{Q_i} * 100\% \quad (11)$$

Where Lc - is the water conveyance loss expressed as a percentage [%], and Qi & Qo - is the total water flowing into and out of a specific section of the canal (l /s).

2.9.3. Field Application Efficiency

The field application ratio for surface irrigation should be found between 0.6 and 0.92 [15]. The field application ratio (Ea) has the same structure as the overall consumed ratio. It is defined as [15].

$$\text{Ea} = \frac{ETp - Pe}{Volume\ of\ water\ delivered\ at\ field(s)} \quad (12)$$

Where ETp is potential evapotranspiration by the irrigated crop and Pe is the effective part of the precipitation.

2.9.4. Overall Scheme Efficiency

The overall scheme efficiency (Ep) was calculated as the product of conveyance (Ec) and application efficiency (Ea). It was computed using the following formula [16].

$$\text{Ep} = \text{Ec} * \text{Ea} \quad (13)$$

2.10. Physical Performance Indicator

2.10.1. Irrigation Ratio

Physical indicators are related to the changing or losing irrigated land in the command area for different reasons. The selected indicator used for the evaluation of physical performance was the irrigation ratio which can be expressed as follows [11, 15].

$$\text{IR} = \frac{Current\ irrigated\ area}{Designed\ command\ arae} \quad (14)$$

Where IR is the irrigation ratio in %, current Irrigated area (ha) is the portion of the irrigated land (ha) in any given Irrigation season, and command area (ha) is the potential scheme command area.

2.10.2. Effectiveness of Infrastructures

Three basic goals of maintenance are intended to be attained: safety, maintaining canals in a condition that minimizes Seepage and maintains canal water ranges and the supposed discharge head dating, and keeping water manipulated infrastructure. The conveyance efficiency of Irrigation systems is the finest means of determining whether canal maintenance is necessary. It should be possible to construct parameters that let you know when canal cleaning or reshaping is needed by way of tracking the adjustments in conveyance efficiencies over time. Instead of taking a more analytical approach, this is frequently done subjectively based on appearance in many systems. The effectiveness of infrastructure is the ratio of the number of functioning structures over the total number of structures to be installed during construction time [11, 15].

$$EI = \frac{Number\ of\ functioning\ structures}{Total\ number\ of\ structures} \tag{15}$$

2.10.3. Water Surface Elevation Ratio

The water surface elevation ratio (WSER) is an important indicator that aims to assess the impact of sedimentation and erosion problems on the main canal of the irrigation scheme [11, 16]. The water surface elevation ratio (WSER) can be calculated as [17].

$$WSER = \frac{Current\ water\ surface\ elevation\ at\ FSL}{Required\ water\ surface\ elevation\ at\ FSL} \tag{16}$$

3. Results and Discussions

3.1. Rainfall Data Analysis

The minimum and maximum rainfall amount occurs in January (16.8 mm) and August (334mm), respectively. The study area has an average total annual rainfall of 1899.6 mm. Scheduling irrigation based on crop demand requires an estimate of effective precipitation or rainfall. Effective rainfall estimates are also important for planning cropping sequences in irrigation crop production. Effective rainfall is the amount of rainfall stored in the crop root zone. Rainfall that runs off the soil surface or passes through the root zone does not contribute to crop growth and yield. As can be seen from Table 2 the highest effective rainfall occurs during August and is about 158.4mm. The total annual effective rainfall of the area is 1106.4mm.

Table 2. *Monthly effective rainfall of the area (USDA S.C Method).*

From 1992-2021 G.C		
Month	**Rainfall depth (mm)**	**Effective rainfall (mm)**
January	16.8	16.3
February	20.4	19.7
March	45.6	42.3
April	98.3	82.8
May	232.7	146.1
June	322	157.2
July	321.5	157.2
August	334	158.4
September	300.9	155.1
October	140.4	108.9
November	46.6	43.1
December	20.2	19.5
Average	158.3	92.2

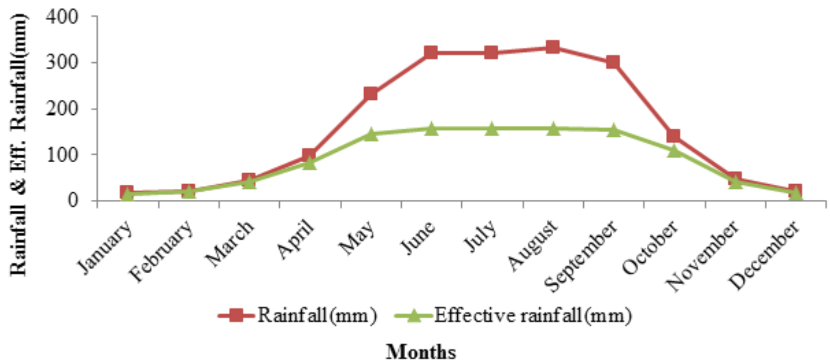

Figure 5. *Relationship between rainfall and effective rainfall.*

***Table 3**. Monthly reference evapotranspiration ETo (CROPWAT output) for the study area.*

Month	Min Temp ℃	Max Temp ℃	Humidity %	Wind km/day	Sun Hours	Rad MJ/m²/day	ETo mm/day
January	13.1	26.9	61	95	7.9	19.2	3.76
February	14.8	29	55	112	7.7	20.2	4.35
March	16.3	30.5	55	121	7.4	20.7	4.77
April	17	29.2	61	112	7.2	20.5	4.62
May	16.8	26.7	74	78	5.6	17.7	3.76
June	15.9	23.6	84	69	4.3	15.4	3.1
July	15.1	22.3	87	104	3.3	14.1	2.76
August	15.1	23.3	87	78	3.4	14.4	2.83
September	15.4	24.5	85	78	4.2	15.8	3.12
October	14.3	24.9	76	104	6.7	18.7	3.65
November	12.9	25.6	71	104	7.3	18.5	3.6
December	12.4	25.8	66	104	7.3	17.9	3.5
Average	14.9	26	72	96	6	17.8	3.65

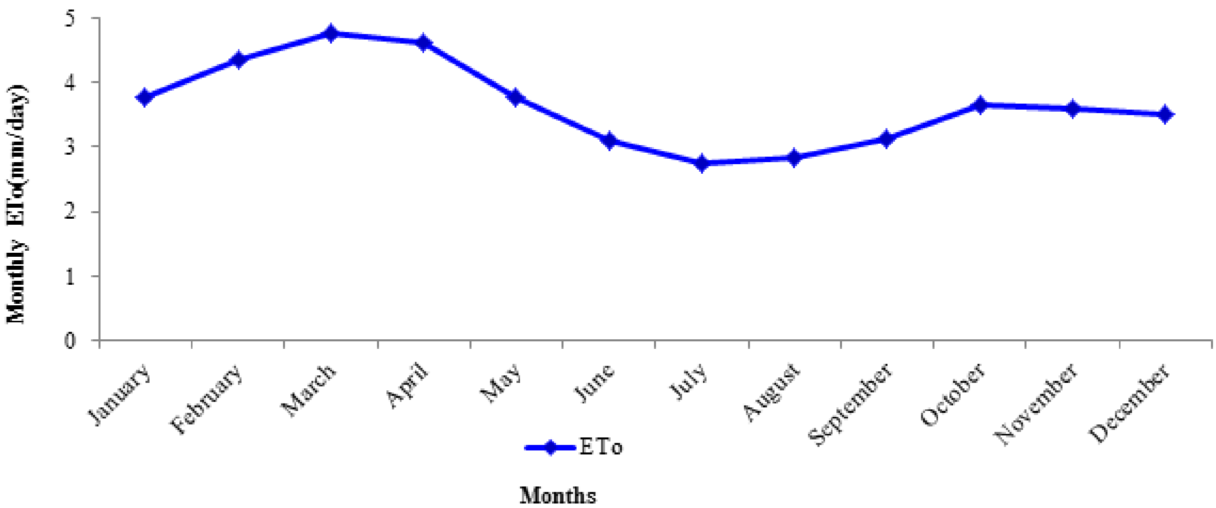

***Figure 6**. ETo variation on each month.*

3.2. Determination of Reference Evapotranspiration (ETo)

As discussed in the methodology, ETo was determined by CROPWAT 8.0 software using Penman-Monteith equation. Table 3 shows a summary of the monthly ETo in the study area. The minimum and maximum monthly ETo values of the irrigation scheme were 2.76mm/day in July and 4.77mm/day in March. The annual average value of ETo was 3.65mm/day indicated in Table 3.

3.3. Crop and Water Requirements of Major Crops

3.3.1. Crop and Irrigation Water Requirements of Tomato Crop

CropWat8.0 software was used to calculate the crop and irrigation needs of tomato crops. Tomatoes require 399.4 mm of irrigation water overall, according to the computation result by software. The plant could employ 179.7 mm of the effective rainfall that was available. In February and March, the tomato crop has its highest irrigation need, as seen in Table 4. As a result, the highest irrigation demand was recorded in February and March, with 112.1 and 124.1mm/dec, respectively. The reason behind this is that during these months, there was a considerable need for crop water due to the effective rainfall's 5.7 mm depth.

Table 4. *Crop Water Requirements for Tomato crop.*

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.6	2.12	6.4	2.6	6.4
Dec	2	Init	0.6	2.1	21	5.6	15.4
Dec	3	Init	0.6	2.15	23.7	5.5	18.1
Jan	1	Deve	0.61	2.25	22.5	5.6	16.9
Jan	2	Deve	0.73	2.74	27.4	5.2	22.2
Jan	3	Deve	0.87	3.44	37.9	5.7	32.2
Feb	1	Deve	1.01	4.2	42	5.6	36.4
Feb	2	Mid	1.13	4.9	49	5.7	43.3
Feb	3	Mid	1.14	5.12	41	8.5	32.4
Mar	1	Mid	1.14	5.28	52.8	11.1	41.8
Mar	2	Mid	1.14	5.44	54.4	13.3	41.1
Mar	3	Mid	1.14	5.39	59.2	18.1	41.2
Apr	1	Late	1.09	5.07	50.7	22.4	28.3
Apr	2	Late	0.96	4.45	44.5	26.6	18
Apr	3	Late	0.84	3.65	36.5	33.9	2.6
May	1	Late	0.77	3.14	3.1	4.3	3.1
Total					572.1	179.7	399.4

The crop water requirement graph for tomato crops represents the amount of water needed by the crop at different growth stages to achieve optimal yields and quality. The graph typically includes a horizontal axis representing time (in days or weeks) and a vertical axis representing the amount of water needed (in millimeters). Understanding the crop water requirement graph for tomatoes is important for farmers to optimize irrigation scheduling and conserve water resources while ensuring optimal yields and quality.

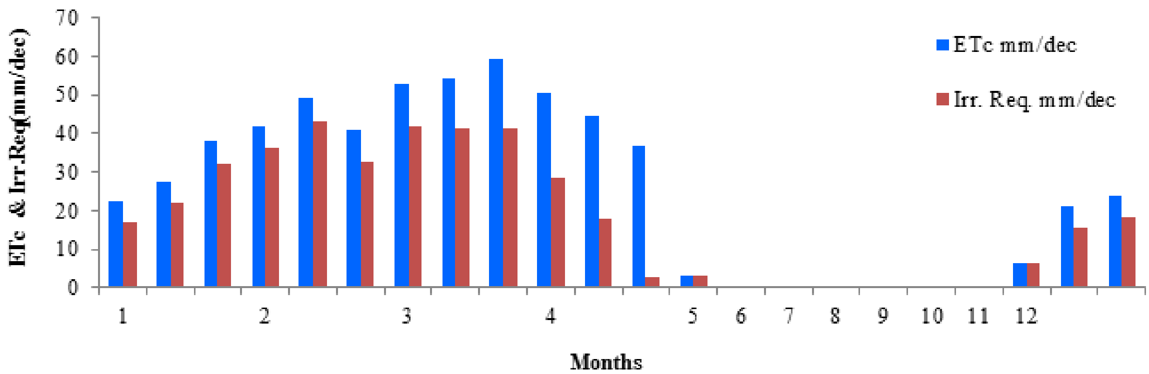

Figure 7. *Crop water requirement graph of Tomato crop.*

An irrigation schedule for tomatoes refers to a plan for applying water to the crop at regular intervals throughout the growing season. The schedule is designed to provide the crop with the right amount of water at the right time to meet its water requirements and ensure optimal growth, yield, and quality.

Table 5. Irrigation schedule of Tomato.

Date	Day	Stage	Rain mm	Ks Fract.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss Mm	Gr. Irr mm	Flow l/s/ha
6-Jan	30	Init	0	1	100	30	50.3	0	0	71.9	0.28
14-Feb	69	Dev	0	1	100	40	116.2	0	0	165.9	0.49
15-Mar	98	Mid	0	1	100	41	120	0	0	171.4	0.68
1-May	End	End	0	1	0	32					
	Total						286.5			409.2	1.45

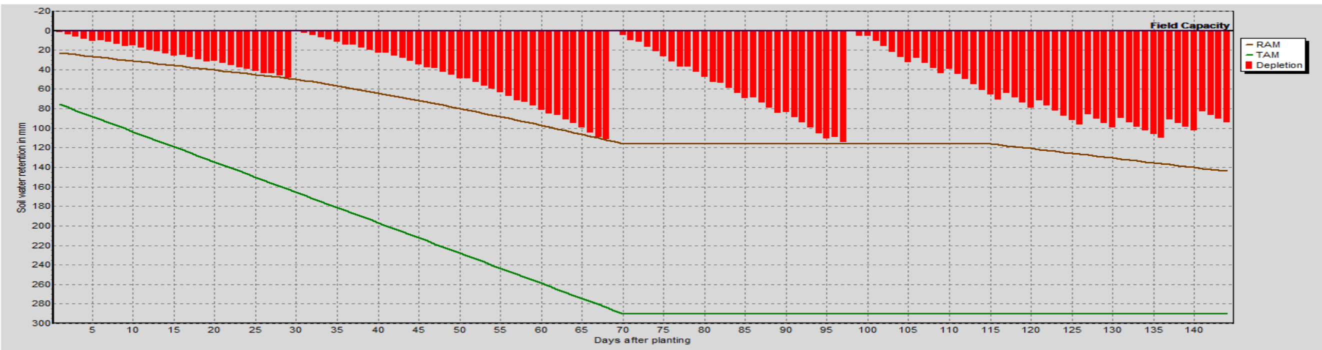

Figure 8. Irrigation scheduling graph of Tomato.

An irrigation scheduling for tomatoes is a visual representation of the crop's water requirements at different growth stages and the amount of water applied through irrigation as shown in Figure 8. The graph typically shows the soil moisture level, rainfall, and irrigation events over time.

3.3.2. Crop Water Requirements of Potato Crop

35 percent of the irrigated land was planted with potatoes, according to the field survey. Table 6 shows the results of the calculations for the effective rainfall and irrigation water requirements. Crop water requirements of potatoes refer to the amount of water needed by the potatoes crop at different stages of growth to achieve optimal yields and quality. The water requirements of potatoes are influenced by various factors such as temperature, humidity, wind, soil type, and crop management practices. The crop water requirement of potatoes can be determined using a crop water requirement graph, which represents the amount of water needed by the crop at different stages of growth. The graph typically includes a horizontal axis representing time (in days or weeks) and a vertical axis representing the amount of water needed (in millimeters).

Table 6. Crop water requirements of Potato crop.

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	3	Init	0.5	1.78	14.3	8.4	3.8
Dec	1	Init	0.5	1.77	17.7	8.5	9.2
Dec	2	Deve	0.51	1.79	17.9	5.6	12.4

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	3	Deve	0.69	2.48	27.3	5.5	21.7
Jan	1	Deve	0.91	3.36	33.6	5.6	28
Jan	2	Mid	1.11	4.16	41.6	5.2	36.4
Jan	3	Mid	1.14	4.5	49.5	5.7	43.9
Feb	1	Mid	1.14	4.72	47.2	5.6	41.6
Feb	2	Mid	1.14	4.95	49.5	5.7	43.7
Feb	3	Mid	1.14	5.11	40.9	8.5	32.3
Mar	1	Late	1.09	5.05	50.5	11.1	39.4
Mar	2	Late	0.96	4.58	45.8	13.3	32.5
Mar	3	Late	0.82	3.87	42.6	18.1	24.5
Apr	1	Late	0.74	3.46	3.5	2.2	3.5
	Total				481.7	109	372.9

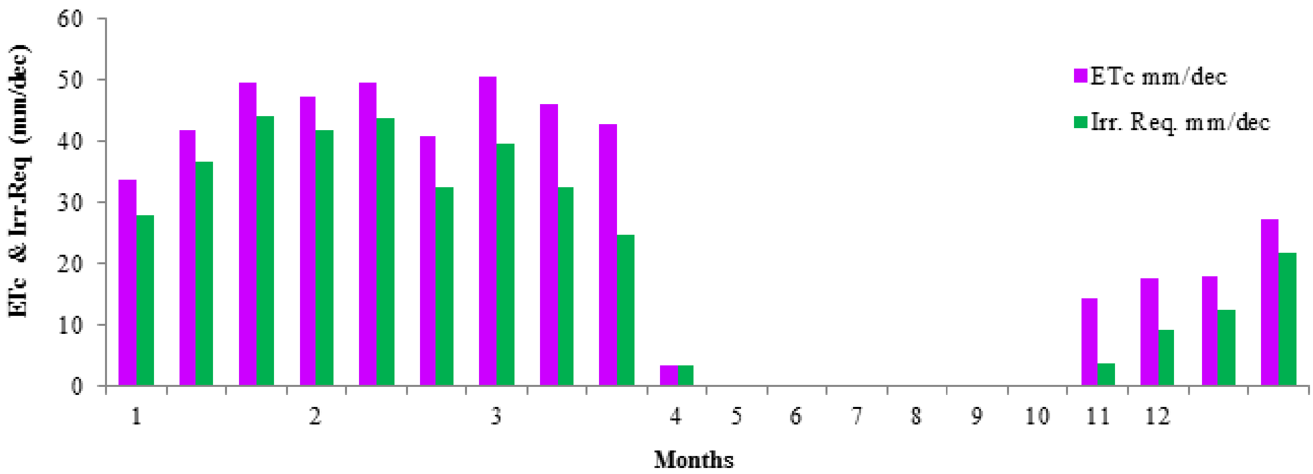

Figure 9. *The crop water requirement graph of Potato crop.*

As indicated by Table 6 and Figure 9, irrigation was required for the duration of the crop's growth season. The potato crop's water needs peaked in January and February of that year. Therefore, 108.3 mm and 117.6 mm, respectively, were the amounts of peak irrigation demand in January and February. 109 mm of effective rainfall is anticipated to be available for plant use, while the total irrigation water requirement for the potato growing season was 372.9 mm.

3.3.3. Crop Water Requirements of Pepper

According to the field survey, pepper was grown on 12% of all irrigated acreage. The software's computation output showed that 335.8 mm of irrigation water was needed overall for pepper. There was 121.1 mm of effective rainfall that the plants could use. As can be observed in Table 7, Crops required irrigation for the whole of their growing season. The peak irrigation demand was recorded in February and March, with corresponding values of 102.3 mm and 108.3 mm. During the pepper growing season, 335.8 mm of irrigation water was needed overall, and 121.1 mm of effective rainfall was estimated to be available for plant use. Table 7 shows the results of the calculation of the effective rainfall and irrigation water requirements.

Table 7. *Crop water requirements of pepper.*

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.6	2.12	2.1	0.9	2.1
Dec	2	Init	0.6	2.1	21	5.6	15.5
Dec	3	Init	0.6	2.16	23.7	5.5	18.2
Jan	1	Deve	0.6	2.22	22.2	5.6	16.6
Jan	2	Deve	0.69	2.61	26.1	5.2	20.9
Jan	3	Deve	0.83	3.27	36	5.7	30.3
Feb	1	Deve	0.96	3.98	39.8	5.6	34.1
Feb	2	Mid	1.04	4.51	45.1	5.7	39.4
Feb	3	Mid	1.04	4.66	37.3	8.5	28.8
Mar	1	Mid	1.04	4.81	48.1	11.1	37.1
Mar	2	Mid	1.04	4.96	49.6	13.3	36.3
Mar	3	Late	1.02	4.82	53	18.1	34.9
Apr	1	Late	0.94	4.4	44	22.4	21.6
Apr	2	Late	0.89	4.11	12.3	8	0
	Total				460.4	121.1	335.8

A crop water requirement graph for pepper is a visual representation of the amount of water that the crop needs at different stages of growth. The graph typically includes a horizontal axis representing time (in days or weeks) and a vertical axis representing the amount of water needed (in millimeters). The crop water requirement graph for pepper is based on several factors, including the crop's evapotranspiration rate (ETo), which is the amount of water lost through evaporation from the soil and transpiration from the plant's leaves.

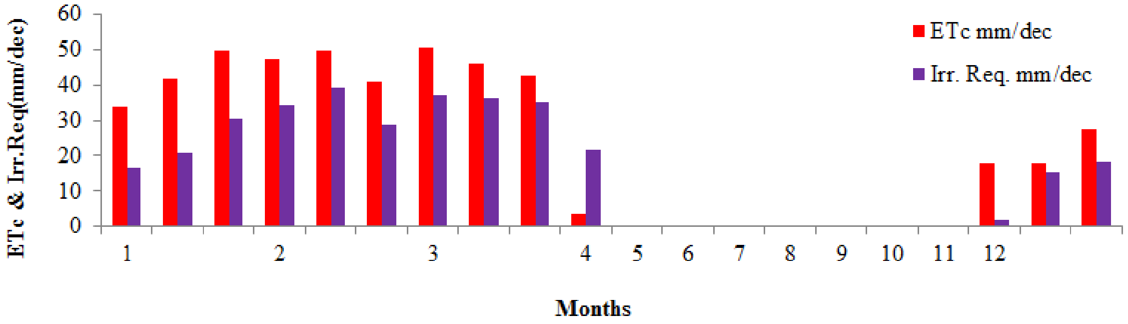

Figure 10. *Crop water requirement graph of Pepper crop.*

3.3.4. Crop Water Requirements of Wheat

According to the field survey, wheat occupied 38% of the total irrigated land. Table 8 shows the calculated effective rainfall and irrigation water requirements. Irrigation was required for the whole crop's growing season. The wheat crop's water consumption peaked in February and March. Therefore, during February and March, the amount of irrigation demand that peaked was 117.7 mm and 103.6 mm, respectively. During the wheat growing season, 298.9 mm of irrigation water was needed, while 125.4 mm of effective rainfall was predicted to be available for plant use.

Table 8. *Crop Water Requirements of Wheat.*

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.3	1.06	6.4	5.1	2.1
Dec	2	Init	0.3	1.05	10.5	5.6	4.9
Dec	3	Init	0.3	1.08	11.8	5.5	6.3
Jan	1	Deve	0.38	1.39	13.9	5.6	8.3
Jan	2	Deve	0.65	2.44	24.4	5.2	19.2
Jan	3	Deve	0.94	3.73	41	5.7	35.4
Feb	1	Mid	1.14	4.72	47.2	5.6	41.5
Feb	2	Mid	1.14	4.95	49.5	5.7	43.8
Feb	3	Mid	1.14	5.11	40.9	8.5	32.4
Mar	1	Mid	1.14	5.27	52.7	11.1	41.7
Mar	2	Late	1.08	5.15	51.5	13.3	38.2
Mar	3	Late	0.8	3.79	41.7	18.1	23.7
Apr	1	Late	0.51	2.38	23.8	22.4	1.4
Apr	2	Late	0.33	1.52	4.5	8	0
	Total				420	125.4	298.9

The graph may include different lines or bars representing different irrigation treatments or soil moisture levels. For example, one line may represent the actual amount of water received by the crop, while another line may represent the ideal amount of water needed based on local weather conditions and soil type.

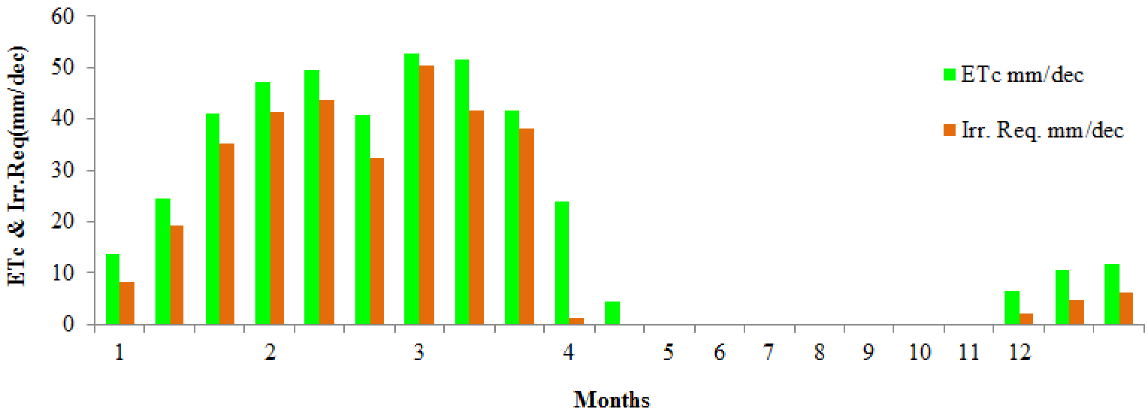

Figure 11. *Crop water requirements graph of wheat.*

Cropwat8.0 was used to compute the irrigation scheduling, as indicated in Table 13. This makes it easier to assess and compare the selected fields' efficiencies to the optimal and helps to establish similar conditions with the farmers' irrigation techniques. Because farmers are unable to assess and monitor the soil moisture levels of the soil before irrigation, scheduling should take application strategies into account throughout the growing stages. These options need to be carefully considered, with recommendations based on local studies.

Table 9. *Irrigation schedule of Wheat.*

Date	Day	Stage	Rain mm	Ks Fract.	Eta	Depl	Net Irr Mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
28-Feb	86	Mid	0	1	100	56	194.8	0	0	278.3	0.37
13-Apr	End	End	53.3	1	100	25					
	Total						194.8			278.3	0.37

An irrigation scheduling for wheat is a visual representation of the recommended frequency and amount of water to be applied to the crop at different stages of growth as indicated in Figure 12. The graph typically includes a horizontal axis representing time (in days or weeks) and a vertical axis representing the amount of water to be applied (in millimeters).

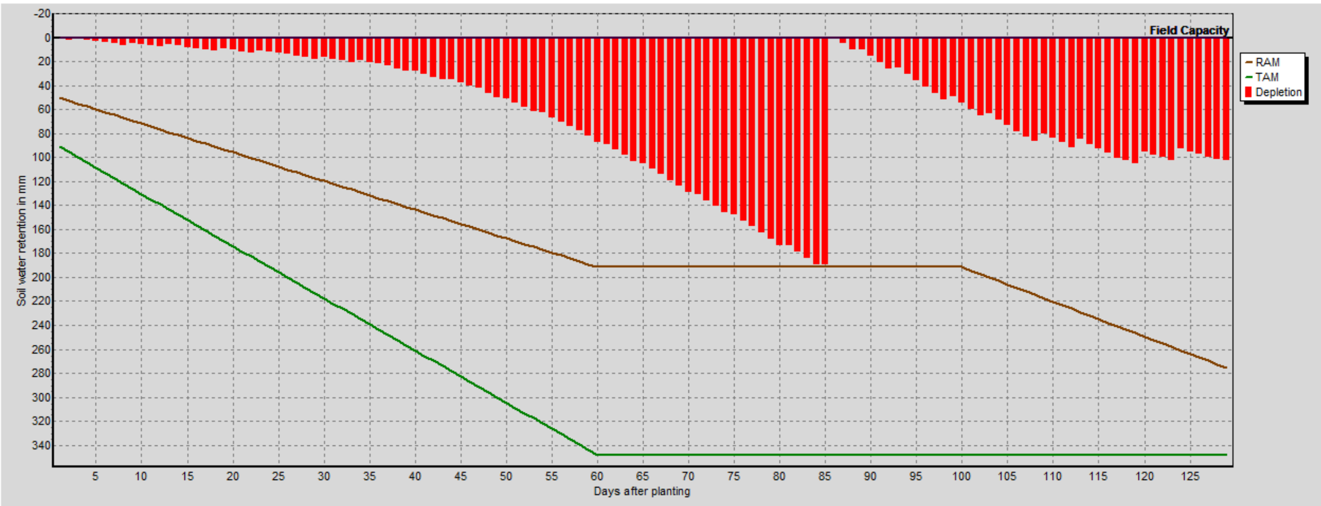

Figure 12. *Irrigation scheduling graph of wheat.*

3.4. Results of Conveyance Efficiency

The operating gates regulate the canal's discharge. A diversion weir also controls the main source, the Jato stream, from which the discharge in the main canals varies periodically. There are several constructions built on the main canals, division box, and turnout. The following tables list the water flow measurement results for Jato's small-scale Irrigation scheme, with a weir installed in the main canal on February 20, March 22, and April 26, 2023 G.C.

Measurements taken in this during the dry season in February, March, and April indicate that the average discharge of 43 liters per second is within the average of 53.6 45.4 & 29.9 liters per second. The conveyance efficiency varied within the day, at the head, middle, and tail sections during the season of the scheme as can be seen in Tables 10, 11, &12. The average conveyance efficiency of the lined main canal was 70% as indicated in Table 13.

The average conveyance efficiency should be 75% for concrete-lined canals. Since the value of conveyance efficiency of the canal is less than 1 there is water loss in the main canal and therefore a need for maintenance of the system. The amount of water lost will determine the need for maintenance of the system. It is recommended that the conveyance efficiency of the concrete lined -canal should be above 75%.

Table 10. *Water flow measurement results for Day 1 on February 20, 2023 G.C.*

Type of canal	Station	Time symbol	Measure-ment(sec)	Width (m)	Depth of water in canal(m)	Surface veloci-ty(m/s)	Correc-tion factor	Mean Veloci-ty(m/s)	Area(m2)	Q(l/s)
Lined main canal	Head	T1	34	0.4	0.4	0.44	0.85	0.37		
		T2	33	0.4	0.4	0.45	0.85	0.38		
		T3	34	0.4	0.4	0.44	0.85	0.37		
		Avg	33.7	0.4	0.4	0.45	0.85	0.38	0.16	60.8
Lined main canal	Middle	T1	35	0.4	0.35	0.43	0.85	0.37		
		T2	34	0.4	0.35	0.44	0.85	0.37		
		T3	37	0.4	0.35	0.41	0.85	0.35		
		Avg	35.3	0.4	0.35	0.43	0.85	0.37	0.14	51.8
Unlined main canal	Tail	T1	41	0.4	0.35	0.43	0.85	0.37		
		T2	45	0.4	0.28	0.33	0.85	0.28		
		T3	43	0.4	0.28	0.35	0.85	0.30		
		Avg	43	0.4	0.28	0.35	0.85	0.30	0.11	33

Table 11. *Water flow measurement results for Day 2 on March 22, 2023 G.C.*

Type of canal	Station	Time symbol	Measure-ment(sec)	Width (m)	Depth of water in canal(m)	Surface veloci-ty(m/s)	Correc-tion factor	Mean Veloci-ty(m/s)	Area(m2)	Q(l/s)
Lined main canal	Head	T1	37	0.4	0.36	0.41				
		T2	35	0.4	0.36	0.41	0.85			
		T3	36	0.4	0.36	0.41				
		Avg	36	0.4	0.36	0.41	0.85	0.35	0.15	52.5
Lined main canal	Middle	T1	37	0.4	0.32	0.41				
		T2	36	0.4	0.32	0.42	0.85			
		T3	39	0.4	0.32	0.39				
		Avg	37.3	0.4	0.32	0.40	0.85	0.34	0.13	44.2
Unlined main canal	Tail	T1	43	0.4	0.28	0.35				
		T2	47	0.4	0.28	0.32	0.85			
		T3	45	0.4	0.28	0.33				
		Avg	45	0.4	0.28	0.33	0.85	0.28	0.11	30.8

Table 12. Water flow measurement results for Day 3 on April 26, 2023 G.C.

Type of canal	Station	Time symbol	Measure-ment(sec)	Width (m)	Depth of water in canal(m)	Surface veloci-ty(m/s)	Correc-tion factor	Mean Veloci-ty(m/s)	Area(m2)	Q(l/s)
Lined main canal	Head	T1	38	0.4	0.34	0.40				
		T2	37	0.4	0.34	0.41	0.85			
		T3	38	0.4	0.34	0.40				
		Avg	37.7	0.4	0.34	0.40	0.85	0.34	0.14	47.6
Lined main canal	Middle	T1	40	0.4	0.32	0.38				
		T2	42	0.4	0.32	0.36	0.85			
		T3	42	0.4	0.32	0.36				
		Avg	41.3	0.4	0.32	0.36	0.85	0.31	0.13	40.3
Unlined main canal	Tail	T1	48	0.4	0.25	0.31				
		T2	45	0.4	0.25	0.33	0.85			
		T3	49	0.4	0.25	0.31				
		Avg	47.3	0.4	0.25	0.32	0.85	0.27	0.1	27

Table 13. Average conveyance efficiency & loss in the lined &unlined main canal.

Canal type	Required inflow	Head	Middle	Tail	Average outflow	CE	CL
	l/s	l/s	l/s	l/s	l/s	%	%
LMC & UMC	61.15	53.6	45.4	30.3	43	70	30

3.5. Physical Performance Indicators Results

3.5.1. Irrigation ratio

Physical indicators are related to the changing or losing irrigated land in the command area for different reasons. The irrigation ratio of the Jato small-scale irrigation scheme was 80 which means about 20% of the command area of the scheme was not under irrigation during the study period as indicated in Table 14. The computed values of the sustainability irrigated area of the Jato scheme were below one, which indicated that the current irrigated area was below the proposed values during the construction period of the irrigation scheme. The reduction of the command area was due to water scarcity and poor maintenance activity of the scheme.

Table 14. Data of command areas and value of Physical indicator of the scheme.

Jato irrigation command area	Unit	Extent
Required irrigated area	ha	75
Current irrigated area	ha	60
Irrigation ratio	%	80

3.5.2. Effectiveness of infrastructures

The effectiveness of infrastructure is a critical factor in the success of the Jato small-scale irrigation scheme. The studies have shown that infrastructure accounts for up to 66.7% of the value of the Jato small-scale irrigation scheme as indicated in Table 15. Effective infrastructure can improve the conveyance efficiency of canals, reduce water losses due to seepage and evaporation, and provide reliable water sources for irrigation. This can lead to increased crop yields, improved food security, and higher incomes for farmers. However, poorly designed or maintained infrastructure can lead to water shortages, crop failure, and even environmental degradation. Therefore it is important to invest in high-quality infrastructure and ensure that it is properly maintained over time. This requires ongoing investment and support from governments, NGOs, and other stakeholders to ensure that the Jato small-scale irrigation scheme can continue to provide benefits to farmers and communities over the long term.

Table 15. *Observed structures status*

List of Structure	№ of Structures	Partly functioning	Fully Functioning	% of Fully Functioning
Intake	12	8	4	33.33
Diversion Weir	1	0	1	100
Sluice gate	1	1	0	0
Drainage Culvert	3	2	1	33.33
Division Box	1	0	1	100
Inlet	2	1	1	50
Siphon	2	0	2	100
Foot path	10	2	8	80
chute	8	4	4	50
Turnout	20	2	18	90
Total	60	20	40	66.7

3.5.3. Water Surface Elevation Ratio Result

This parameter is also called canal water level ratio, which is focused on different sections of the main canal and secondary canal. As per the design document shown in Table 16; the required water level depth in the main canal from the bottom was 0.5m at the full supply level. The current average water surface elevation at full supply level was found to be 66% (0.33m) for the main canal section. This shows a 34% of WSE at FSL was reduced from the required water depth of the main canal as shown in Table 16. Therefore, the average WSER through the head, middle, and tail reaches was less than one. In general, the main canal system of the Jato irrigation scheme did not have a maintenance schedule to remove sediment buildup and weed incidence.

Table 16. *Overall average WSER in the main canal*

Type of canal	Required(m)	Current(m)	WSER (%)
Lined & Unlined MC	0.5	0.33	66

4. Conclusions

Assessing the performance of the conveyance system of the Jato small-scale irrigation scheme is the main objective of the study. Assessing the performance of the conveyance system of the Jato small-scale irrigation scheme is the main objective of the study. From investigations made during the study, the conclusions outlined below can be drawn.

1. By using water balance indicators to evaluate the data, the conveyance efficiency is good, with a conveyance efficiency of 70%, and the application efficiency and overall consumed efficiency have values of 70% and 50%, respectively.
2. The results for the Jato small-scale irrigation scheme show that the system is not only unable to provide the required amount of water for the crops but also fails to supply the water concerning the amount of intended water.
3. The indicators' values show that the irrigation effectiveness of infrastructure is low with a value of 66.7%.
4. It was 70% for the field application efficiency. The total consumption efficiency was found to be 50%, which is much less than the optimum efficiency which is one. This demonstrates that the crop is not irrigated using the available water, even when it is insufficient. It is evident from the scenario that the water provided by the program is not only used for irrigation purposes but also serves as a source of drinking water for animals.
5. With a conveyance of 70%, the main canal's capacity to not satisfy peak crop demand is indicated by a number that is less than one. In general, this indicates that the channel can transport water from the sources to the fields if it is available.
6. The effectiveness of a structure is the number of structures in good conditions, divided by the total number of structures. Poor can be defined as not functioning adequately, or the risk of failing and the ideal optimum is one. At the farmers' field level, there was a glaring lack of irrigation water management. Because farmers' management expertise is significantly below what was applied, low efficiency was attained.
7. Farmers were applying excess amounts of water to their fields without considering the crop water requirement of the crop.
8. In conclusion, assessing the performance of a conveyance system in the Jato small-scale irrigation scheme is critical to ensure that the system is functioning efficiently and effectively. By identifying any issues and implementing appropriate solutions, farmers can maximize their crop yields while minimizing water wastage and energy consumption.

5. Recommendations

The following recommendations were drawn from the assessing the performance of the conveyance system of the Jato small-scale irrigation scheme:

1. It is recommended that night storage be designed that can be used to store water during off-peak hours and release it during peak hours when the water demand is higher.
2. It is also recommended that farmers be made aware of the system through the Water Users Association to motivate them to take part in its maintenance.
3. Efficient infrastructure such as pipes and distribution networks be designed to minimize water loss and maximize water delivery to the crops is necessary.
4. Around the head structure the soil exists with sand, gravels and within an irregular form the weathered basalt rock is exposed, which makes a laborious to excavate. In this mentioned area existed the water seepage and eroded problems that need the necessary measures.
5. Along the weir axis from the right side there is soil, gravel, and pebble size which cause seepage, erode, and head work slide if not excavated.
6. It is recommended that establishing a system for regular monitoring and evaluation of the performance of the project is a vital role in identifying any challenges or areas for improvement, ensuring the project remains effective and sustainable.
7. Additional efforts are necessary to pinpoint any issues and address them effectively, or propose viable remedies.

Author Contribution

Abera Asefa: Analyzed and interpreted the data; materials, analysis tools or data; Wrote the paper

Dereje Adeba: Advisor, Conceptualization, Methodology analysis tools or data

Gemechu Mosisa: Conceptualization, analysis tools or data, Data curation, Methodology, Writing - review & editing

Data Availability

All information provided to this publication is presented in the full document/the data that has been used is confidential.

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Conflicts of Interest

The author declares that they have no conflicts of interest.

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