

Performance Evaluation of the Erer Irrigation Scheme: A Case Study of the Irsha Limat Irrigation Project, Somali Region, Ethiopia

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ABSTRACT

Irrigation plays a critical role in enhancing agricultural productivity and food security particularly in arid and semiarid regions where rainfall is unreliable and the Erer Irrigation Scheme one of the oldest surface irrigation schemes in the Somali Region of Ethiopia has experienced declining performance associated with structural deterioration sedimentation and conveyance losses. This study evaluated the technical, operational and maintenance performance of the scheme during a citrus irrigation season from October 2023 to January 2024 using standardized irrigation performance indicators and field measurements were conducted along the main and secondary canals to determine discharge, flow velocity, water levels and conveyance losses. Crop water requirements were estimated using CROPWAT 8.0 with climatic data obtained from Jigjiga Meteorological Station. The assessed indicators included adequacy, equity, dependability, efficiency, conveyance efficiency, water surface elevation ratio, infrastructure effectiveness and water delivery ratio. Main canal conveyance efficiency ranged from 85.71% to 93.33%, with an average of 89.52%. Mean conveyance efficiency was 67.11% in secondary canal one, 66.15% in secondary canal two and 63.85% in secondary canal three. Mean adequacy values for the three secondary canals were 0.86, 0.76, and 0.79 respectively. Only 19 of 29 originally installed control structures were functional giving an infrastructure effectiveness of 65.5%. Water delivery ratios at the monitored secondary canal offtakes ranged from 0.56 to 0.84. The results indicate that performance deteriorates in several middle and tail reaches and that structural and maintenance constraints are important contributors to water delivery losses and rehabilitation of canal infrastructure improved sediment and vegetation management, improved water scheduling and systematic maintenance are recommended to improve scheme performance and sustainability.

Keywords: irrigation performance evaluation, crop water requirement, water delivery, conveyance efficiency, adequacy, equity, dependability, irrigation efficiency, water surface elevation ratio, infrastructure effectiveness Erers, Ethiopia.

INTRODUCTION

1. Background

Water scarcity is a critical challenge for agricultural production and water resource management and in arid and semiarid areas irrigation is essential for compensating for unreliable rainfall and supporting crop production but irrigation schemes may perform below their design potential because of conveyance losses inadequate maintenance, sedimentation, operational constraints and weaknesses in water distribution.

Performance evaluation provides a quantitative basis for identifying water delivery problems and for comparing actual system performance with crop water requirements. Adequacy, efficiency, dependability and equity are established indicators for evaluating irrigation water delivery systems (Molden & Gates, 1990).

These indicators can be complemented by physical maintenance indicators such as conveyance efficiency water surface elevation ratio, infrastructure functionality and delivery ratio.

The Erer Irrigation Scheme is an important irrigation system in Erer Woreda of the Somali Region and the Erer River is a perennial source used for irrigation by the Erer Gota horticultural/state farm area and local farmers. The scheme has operated for many decades but the present manuscript identified limited recent empirical evidence describing its hydraulic and maintenance performance therefore systematic assessment is important for identifying constraints and supporting rehabilitation and improved water management. The objective of this study was to evaluate the performance of the Erer Irrigation Scheme by assessing crop water requirements, canal conveyance efficiency and losses, water delivery performance and physical maintenance indicators and by identifying major constraints affecting scheme performance.

MATERIALS AND METHODS

2.1 Description of the Study Area

The study area is located approximately 231 km north west of Jijiga town in Erer Woreda, Fadxuli Kebele, Somali Region, Ethiopia and the route includes approximately 105 km of asphalt road between Jijiga and Harar, 60 km between Harar and Dire Dawa and approximately 61 km of gravel road from Dire Dawa to Fadxuli. The Erer irrigation area is historically associated with Erer Gota and citrus production and the first citrus plants were reportedly established in 1945 after which the farm was expanded.

The study area lies approximately between 9°36'30" and 9°38'00" N latitude and 41°23'30" and 41°24'15" E longitude at approximately 1,113 to 1,210 m above sea level.

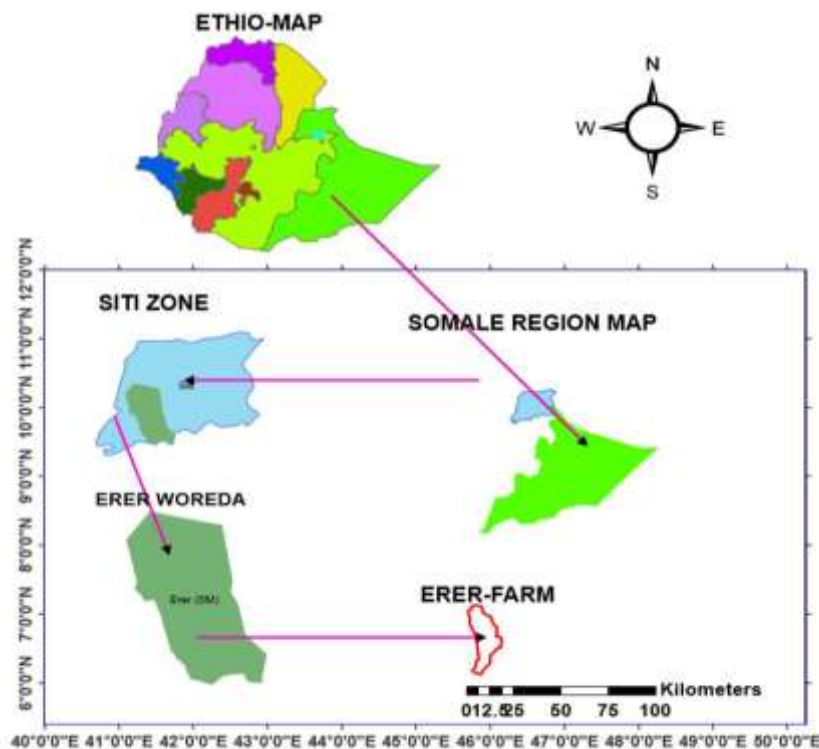


Figure-1 Geographical location of Erer irrigation scheme

2.1.2 Land use

The terrain is generally undulating and rolling while irrigated plots are relatively flat with reported slopes ranging from less than 1% to 7%.

The mean annual rainfall is approximately 626.45 mm. Reported minimum and maximum temperatures are

approximately 18°C and 34.85°C, respectively and annual evapotranspiration is estimated at about 1,800 mm. The soils range from sandy loam to clay loam.

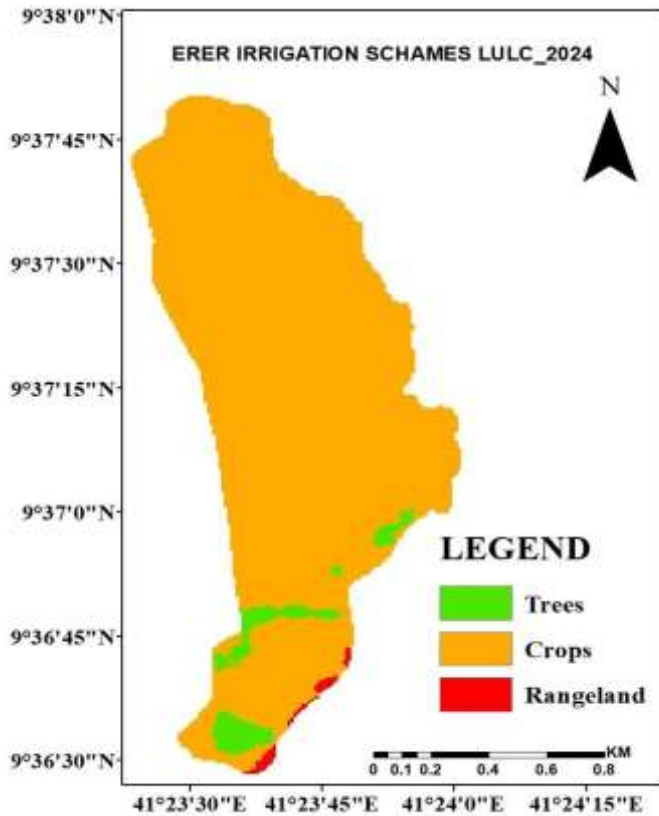


Figure 2 Land use land cover of the Erer irrigation scheme

2.2 Data Sources and Collection

The evaluation covered one citrus irrigation season from October 2023 to January 2024 and primary data consisted of direct field measurements and observations of the main and secondary canals. The secondary information was obtained from the Erer Irrigation Development Project Office and Jigjiga Meteorological Station.

2.2.1 Flow Measurement

The original manuscript described the method as a floating measurement method but then described a rotating cup current meter with an automated revolution counter. To remove this methodological ambiguity the method is described here as a current meter area velocity method and flow velocity was measured using a rotating cup current meter positioned on a rod at the selected measurement sections. The counter recorded cup revolutions from which velocity was obtained according to the instrument calibration. Measurements were taken at canal offtakes and along the main and secondary canals at head, middle and tail reaches. Measurements were conducted on three days per month from October 2023 to January 2024 and average values were used for the analysis and for each measurement section discharge was determined from the measured cross sectional area and mean flow velocity:

$$Q = A \times V$$

where Q is discharge (m³/s)

A is wetted cross sectional area (m²) and

V is mean flow velocity (m/s).

2.3 Crop Water Requirement

CROPWAT 8.0 was used to estimate reference evapotranspiration and crop water requirements for the citrus irrigation season and climate data were obtained from Jigjiga Meteorological Station and crop coefficients were selected according to crop growth stage. The crop reference was corrected throughout the manuscript to citrus the previous isolated reference to sugarcane was a textual inconsistency.

Irrigation Performance Indicators: Formulas and Definitions

Water delivery performance was assessed using adequacy, efficiency, equity and dependability and these indicators are consistent with the framework of Molden and Gates (1990) which uses spatial and temporal distributions of required and delivered water.

The following tables present the irrigation performance indicators used in the revised Erer Irrigation Scheme manuscript, with their formulas and definitions.

Adequacy (PA)

Indicator	Formula	Definition
Adequacy (PA)	$PA = QD / QR$	Measures the ratio of water actually delivered (QD) to the water required (QR). A value closer to 1 indicates that water delivery more closely matches crop water requirements.

Where: QD = delivered discharge; QR = required discharge.

Efficiency (PF)

Indicator	Formula	Definition
Efficiency (PF)	$PF = QR / QD$	Indicates the degree to which the amount of water delivered corresponds to the required water. Values closer to 1 indicate closer matching between delivered and required water.

Where: QR = required discharge; QD = delivered discharge.

Equity (PE)

Indicator	Formula	Definition
Equity (PE)	$PE = 1 / \text{mean}[CVR(QD/QR)]$	Measures the spatial uniformity of the delivered-to-required water ratio among different locations or reaches of the irrigation system.

Where: CVR = spatial coefficient of variation; QD = delivered discharge; QR = required discharge.

Dependability (PD)

Indicator	Formula	Definition
Dependability (PD)	$PD = 1 / \text{mean}[CVT(QD/QR)]$	Measures the temporal consistency of water delivery relative to crop water requirements over time.

Where: CVT = temporal coefficient of variation; QD = delivered discharge; QR = required discharge.

Conveyance Efficiency (Ec)

Indicator	Formula	Definition
Conveyance efficiency (Ec)	$Ec = (Q_{out} / Q_{in}) \times 100$	Measures the percentage of water entering a canal reach that remains available at the outlet of that reach.

Where: Q_{in} = inflow discharge; Q_{out} = outflow discharge.

Conveyance Loss (Lc)

Indicator	Formula	Definition
Conveyance loss (Lc)	$Lc = Q_{in} - Q_{out}$	Measures the quantity of water lost between the inlet and outlet of a canal reach.

Where: Q_{in} = inflow discharge; Q_{out} = outflow discharge.

Water Delivery Ratio (WDR)

Indicator	Formula	Definition
Water Delivery Ratio (WDR)	$WDR = \frac{Q_{actual}}{Q_{design}}$	Measures actual water discharge delivered relative to the design or intended discharge.

Where: Q_{actual} = measured actual discharge; Q_{design} = design/intended discharge.

Infrastructure Effectiveness (IE)

Indicator	Formula	Definition
Infrastructure Effectiveness (IE)	$IE = \left(\frac{N_{functional}}{N_{installed}} \right) \times 100$	Measures the percentage of installed irrigation structures that remain functional and operational.

Where: $N_{functional}$ = number of functional structures; $N_{installed}$ = total number of installed structures.

QD = delivered discharge; QR = required discharge; Q_{in} = inflow discharge; Q_{out} = outflow discharge; Q_{actual} = measured discharge; Q_{design} = design/intended discharge; CVR = spatial coefficient of variation; CVT = temporal coefficient of variation. The adequacy, equity, dependability and efficiency framework follows established irrigation performance literature (Molden & Gates, 1990).

2.5 Data Analysis

Measured discharges were summarized by canal and reach and conveyance efficiency was calculated from inflow and outflow discharge and also crop water requirements estimated with CROPWAT were compared with delivered water to derive water delivery indicators. Physical maintenance indicators were calculated from observed water surface conditions, functional control structures and actual versus intended discharge and the analysis focused on the quantitative field measurements contained in the study dataset.

3. RESULTS AND DISCUSSION

3.1 Crop Water Requirement

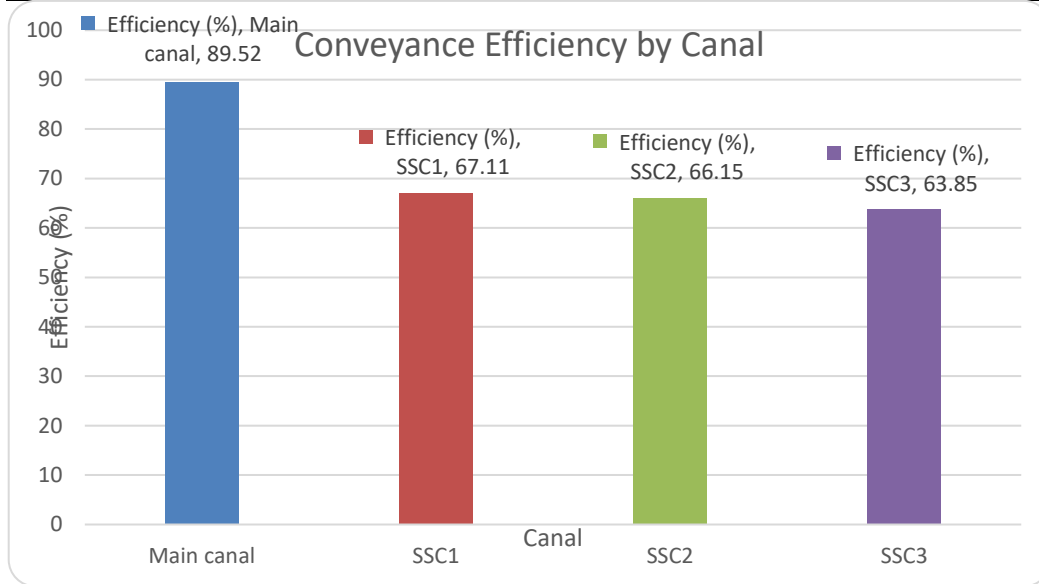
Reference evapotranspiration estimated using CROPWAT 8.0 ranged from 3.96 to 5.44 mm/day during the evaluation period and the crop reference throughout this section is citrus consistent with the stated irrigation season and study design.

Parameter	Reported value
Reference evapotranspiration (ET_0)	3.96–5.44 mm/day
Irrigation season	October 2023–January 2024
Crop evaluated	Citrus

3.2 Water Conveyance Efficiency and Conveyance Losses

The main canal conveyance efficiency ranged from 85.71% to 93.33%, with an average of 89.52%. Conveyance losses at the monitored 200-m reaches were generally 0.01–0.02 m³/s, with an average of approximately 0.015 m³/s at the head and middle reaches and approximately 0.01 m³/s at the tail reach.

Canal	Range of conveyance efficiency	Mean conveyance efficiency
Main canal	85.71–93.33%	89.52%
Secondary canal 1	39.22–95.00%	67.11%
Secondary canal 2	40.00–92.31%	66.15%
Secondary canal 3	31.03–96.67%	63.85%

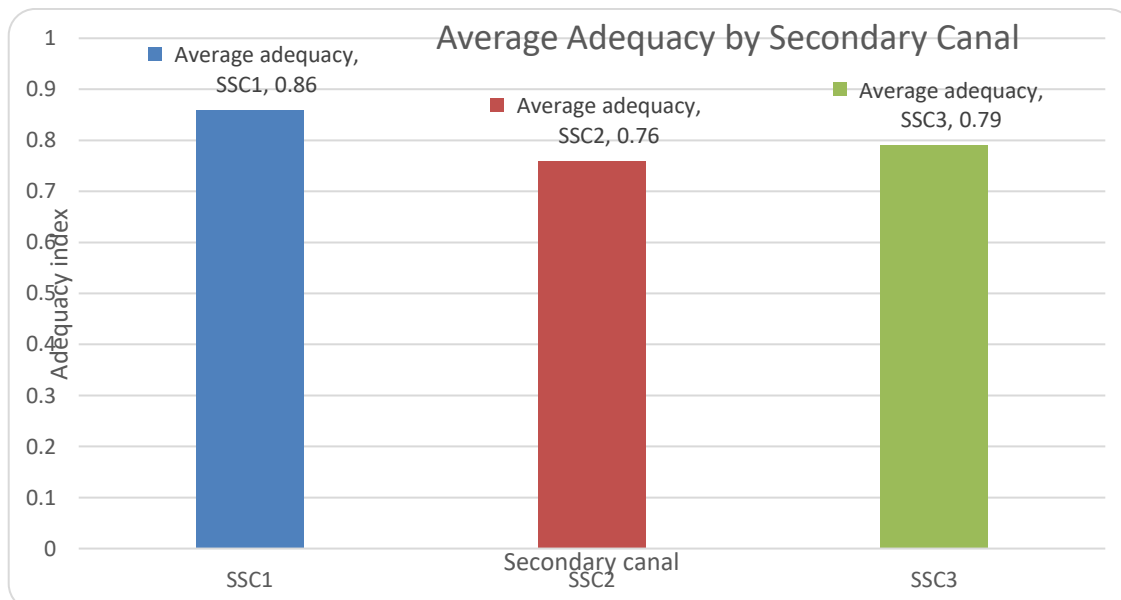


The substantially lower mean efficiencies in the secondary canals indicate greater losses and/or operational variability after water leaves the main canal. The original observations attributed these losses to seepage, cracks, sediment accumulation, and vegetation growth. Because the field record does not provide a quantified contribution for each mechanism, these factors should be interpreted as observed or reported causes rather than separately estimated losses.

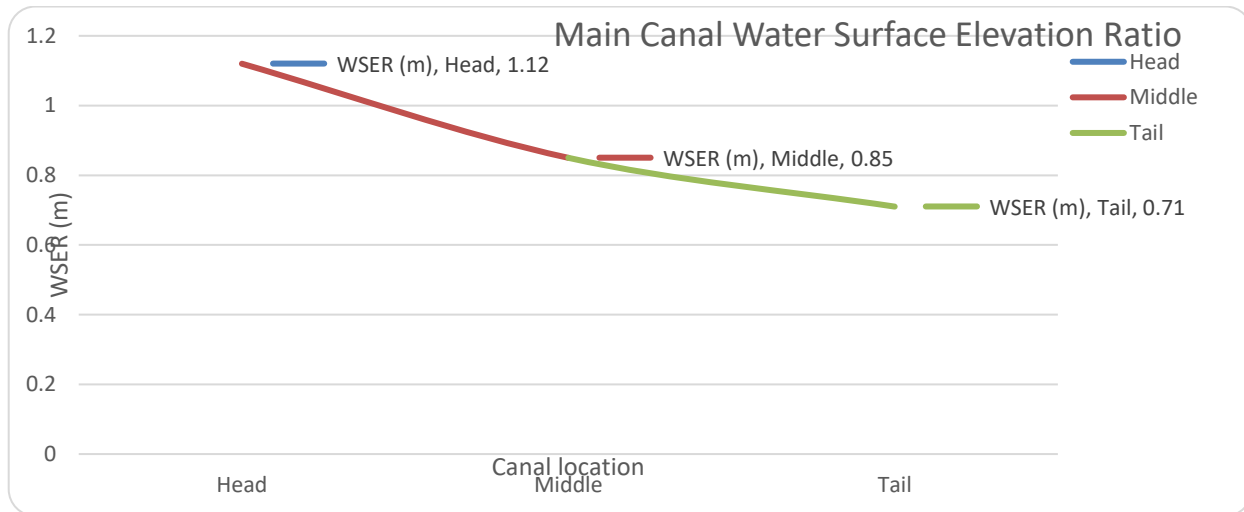
3.3 Irrigation Canal Performance Indicators

3.3.1 Adequacy

Mean adequacy values were 0.86 for secondary canal one, 0.76 for secondary canal two, and 0.79 for secondary canal three. Using the classification reported in the manuscript (good = 0.90–1.00; fair = 0.80–0.89; poor <0.80), secondary canal one was fair, while secondary canals two and three were poor on the basis of their overall means.



The reach specific observations show temporal and spatial variability and in secondary canal one adequacy was generally fair at the head during October and November and poor in December and January the middle and tail reaches showed different monthly patterns. Secondary canal two showed good-to-fair performance at the head, good performance at the middle, and poor performance at the tail. Secondary canal three showed substantial inadequacy at the tail, with poor performance reported for all months at that reach. These patterns indicate that the adequacy problem is not uniform across the network and is particularly evident in some tail reaches.



3.3.2 Equity

Equity values reported for secondary canal one ranged from 0.11 to 0.15 across reaches secondary canal two ranged from 0.00 to 0.15; and secondary canal three ranged from 0.10 to 0.15. The original manuscript incorrectly cited a financial market paper for irrigation equity. That citation has been removed and the interpretation is instead based on the established irrigation-performance framework of Molden and Gates (1990). Under the thresholds used in the manuscript, values of 0.00–0.10 are good, 0.11–0.25 are fair, and values greater than 0.25 are poor.

Secondary canal	Reported equity range	Overall interpretation
SSC1	0.11–0.15	Fair
SSC2	0.00–0.15	Good to fair
SSC3	0.10–0.15	Good to fair

3.3.3 Dependability

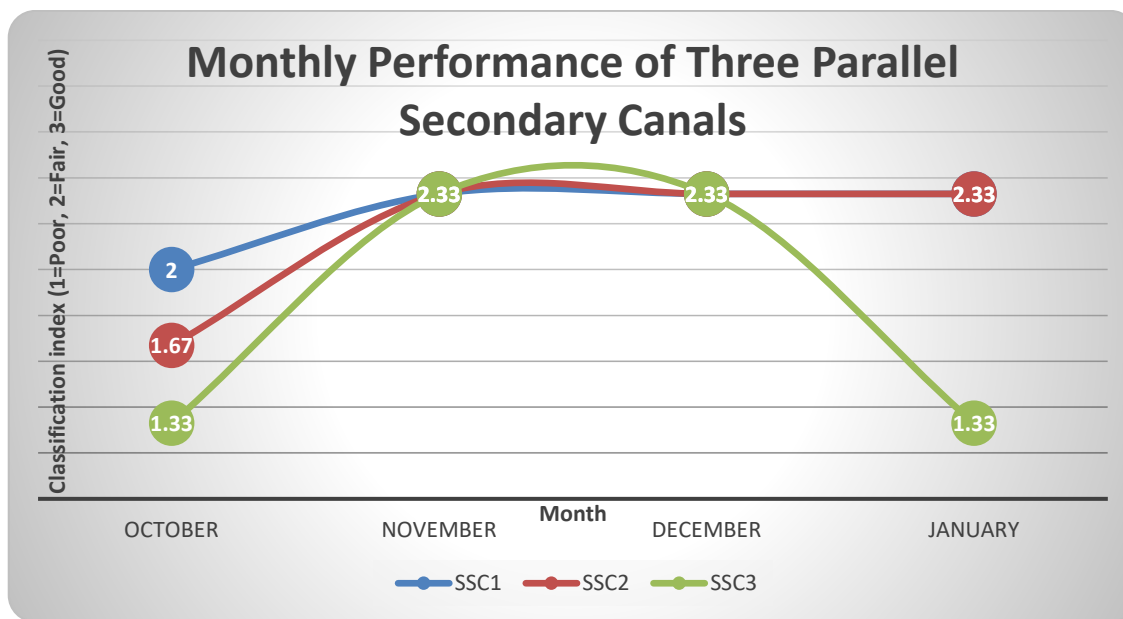
Dependability was assessed using the temporal coefficient of variation of the delivered-to-required water ratio. For secondary canal one, reported values ranged from 0.114 to 0.225 depending on reach and month. Secondary canal two values ranged from 0.032 to 0.127, while secondary canal three values ranged from 0.069 to 0.214. Using the stated classification (good = 0.00–0.10; fair = 0.11–0.20; poor >0.20), the results indicate generally good-to-fair dependability in secondary canal two and more variable performance, including poor observations at the tail of secondary canal three.

Secondary canal	Reported dependability range	Observed pattern
SSC1	0.114–0.225	Fair to poor at some observations
SSC2	0.032–0.127	Good to fair
SSC3	0.069–0.214	Good/fair with poor observations at tail

3.3.4 Efficiency

The efficiency indicator showed reach-specific differences. Secondary canal one was reported as fair at the head and generally good at the middle and tail, with October providing an exception at the middle. Secondary canal two was reported as good at the middle but poor at the head and tail. Secondary canal three was reported as good at the head in most months, fair at the middle, and poor at the tail. The pattern indicates that matching delivered water to crop requirements was less consistent in some head and tail sections, particularly in secondary canals two and three.

The earlier manuscript cited a poorly formatted threshold statement. Rather than repeating the erroneous statement, the revised text describes the observed categories without attributing unsupported thresholds to a specific source.

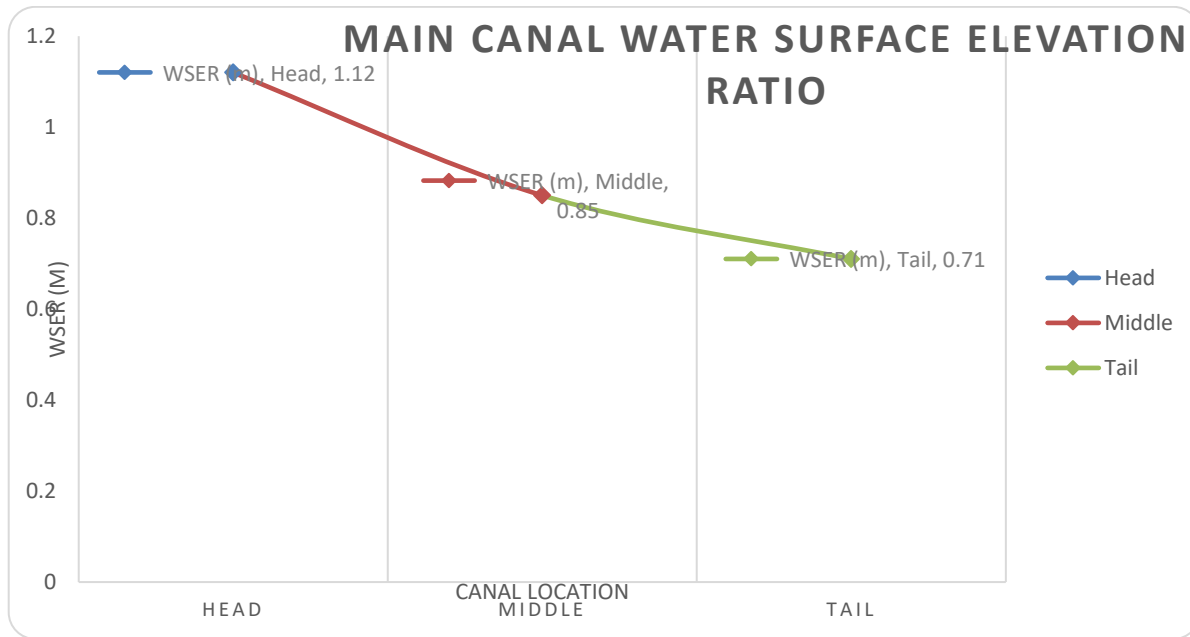


3.4 Maintenance Performance Indicators

3.4.1 Water Surface Elevation Ratio

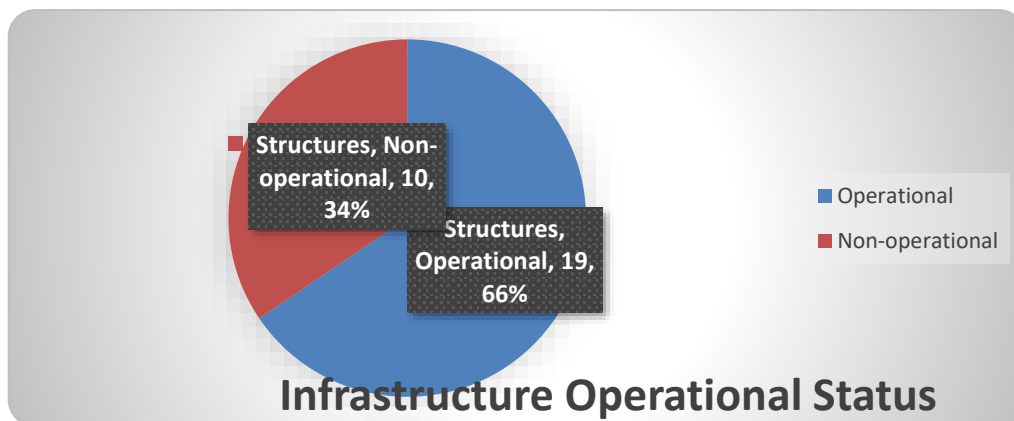
The water surface elevation ratio (WSER) values reported for the main canal were 1.12 at the head, 0.85 at the middle, and 0.71 at the tail. The original manuscript interpreted the lower middle and tail values as evidence of sedimentation and vegetation problems and the head value as indicating possible scouring. These observations are consistent with the field description, although the study does not provide a separate quantified sediment-volume measurement.

Main-canal reach	WSER reported in manuscript	Field interpretation reported
Head	1.12	Possible scouring/high water surface condition
Middle	0.85	Sedimentation/vegetation constraints
Tail	0.71	Sedimentation/vegetation constraints



3.4.2 Infrastructure Effectiveness

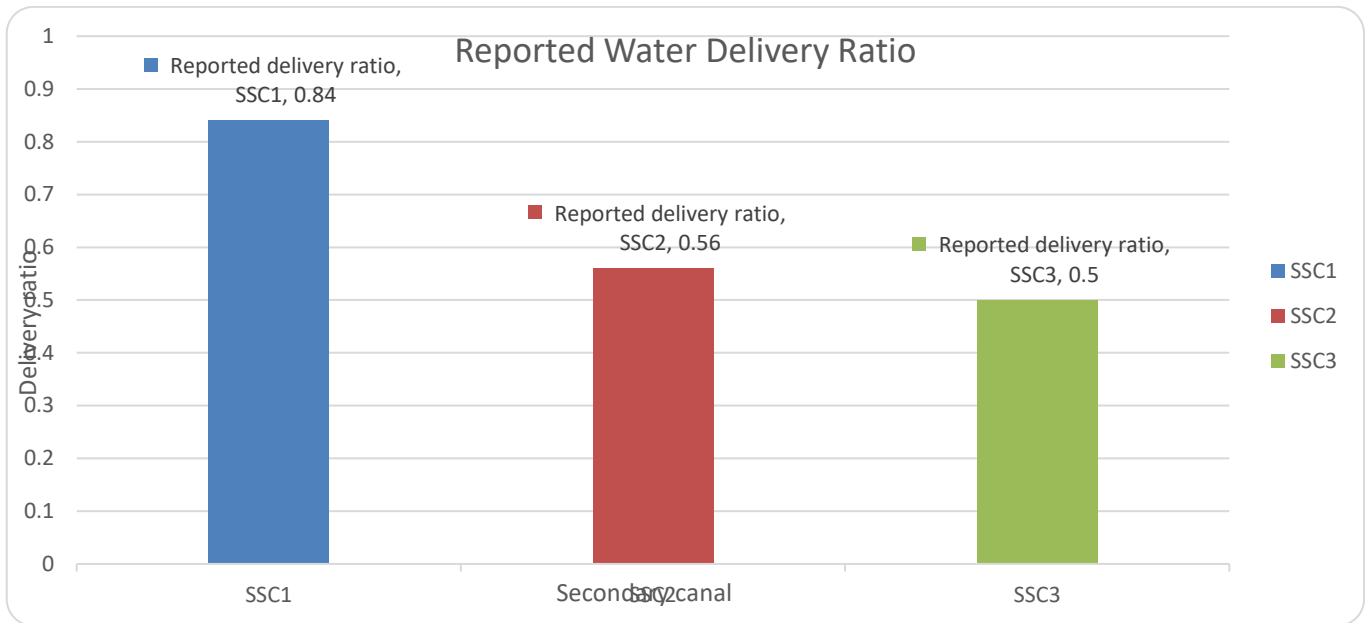
Of the 29 structures originally installed in the scheme, 19 were reported as functional. Infrastructure effectiveness was therefore 65.5% ($19/29 \times 100$). This result indicates that approximately one-third of the originally installed structures were not operational at the time of assessment and highlights a substantial maintenance requirement.



3.4.3 Water Delivery Ratio

The water delivery ratio, defined as actual discharge divided by design or intended discharge, ranged from 0.56 to 0.84 at the monitored secondary-canal offtakes. The manuscript reported approximate losses of 20%, 10%, and 50% relative to design discharge for SSC1, SSC2, and SSC3, respectively. These values indicate that actual delivery was below intended delivery at all three monitored locations.

Indicator	Result
Water delivery ratio range	0.56–0.84
SSC1 reported loss relative to design	20%
SSC2 reported loss relative to design	10%
SSC3 reported loss relative to design	50%
Functional structures	19 of 29
Infrastructure effectiveness	65.50%



The reported maintenance constraints include inadequate maintenance, sediment accumulation, vegetation growth, and structural deterioration. These findings support targeted rehabilitation and routine maintenance of canal sections and control structures.

CONCLUSION

The Erer Irrigation Scheme showed substantial variation in hydraulic and water-delivery performance during the October 2023–January 2024 citrus irrigation season. Main-canal conveyance efficiency was comparatively high, averaging 89.52%, but mean secondary-canal conveyance efficiency was lower, ranging from 63.85% to 67.11%. Adequacy was fair in secondary canal one and poor in secondary canals two and three when evaluated using their reported mean values. Equity and dependability also varied by canal reach and time, with several less favorable observations in middle and tail sections. Physical maintenance indicators showed that only 65.5% of originally installed structures were functional and that actual water delivery at monitored offtakes was below intended discharge.

Overall, the quantitative evidence indicates that rehabilitation and systematic maintenance are required to improve water conveyance and distribution. The study does not provide sufficient quantitative survey data to support the earlier manuscript's statements about farmer satisfaction or Water User Association management; those claims have therefore been removed from the revised abstract, methods, results, and conclusion.

RECOMMENDATIONS

1. Rehabilitate non-functional control structures and prioritize the 10 structures that were reported as non-operational.
2. Implement routine desilting and vegetation control, with particular attention to middle and tail reaches where lower water-surface ratios and delivery problems were reported.
3. Repair canal cracks and other structural defects contributing to seepage and conveyance losses.
4. Strengthen operational water scheduling so that deliveries more closely match crop water requirements at head, middle, and tail reaches.
5. Repeat hydraulic performance measurements after rehabilitation to quantify changes in conveyance efficiency, adequacy, equity, dependability, and delivery ratio.
6. If institutional performance and farmer perceptions are to remain part of the manuscript, the underlying

interview/questionnaire dataset, sampling procedure, results, and analysis should be added before those claims are reintroduced.

LIMITATIONS

The evaluation covered one citrus irrigation season from October 2023 to January 2024. The manuscript contains quantitative hydraulic and maintenance observations but does not contain a complete, traceable qualitative dataset for the farmer/WUA interview component originally mentioned in the abstract. Consequently, institutional perceptions were not analyzed in the revised manuscript. In addition, the available manuscript text did not contain the original numerical datasets underlying every monthly reach-level result; therefore, the revised tables report only values explicitly present in the manuscript.

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