



Performance Evaluation of Kigugu Irrigation Structures

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Abstract

This study assessed the condition and functionality of the Kigugu Irrigation Scheme in Tanzania, chosen due to its unique status as a previously rehabilitated system lacking comprehensive evaluation. Through farmer interviews, visual inspections, and maintenance record reviews, quantitative metrics were employed to evaluate physical integrity, reliability, and maintenance correlations. Results indicate commendable operational functionality (85.7% operational structures), alongside challenges such as non-operational structures and water losses, necessitating targeted attention. Key indices including a overall poor structure index (11.9%), overall reliability index (86.47%), overall maintenance effectiveness (26.85%), and farmer satisfaction (26.85%) underscore areas for improvement. Positive community engagement and ongoing rehabilitation efforts were noted, with identified areas for enhancement spanning infrastructure quality, maintenance, beneficiary participation, and water-saving technologies. A strong correlation (0.969) between commanded area and yields underscores the importance of well-designed irrigation systems. Recommendations encompass targeted maintenance, water loss mitigation, community engagement, and optimization efforts for enhanced functionality and sustainability of the Kigugu Irrigation System.

Keywords · Kigugu Irrigation System, Operational Functionality, Poor Structure Index, Reliability Index, Crop Yield.

1 Introduction

The poor performance of irrigation structures is a significant issue that plagues many irrigation schemes in different global regions, particularly in sub-Saharan Africa (Bjornlund et al., 2020). As reported by Silungwe et al. (2021), irrigation plays a vital role in enhancing agricultural productivity and ensuring food security in many regions around the world. In Tanzania, irrigation schemes are implemented to

optimise water utilisation and support the agricultural sector. However, the effectiveness and performance of irrigation structures within these schemes are crucial factors that determine their success in delivering reliable water supplies to farmers (Mchele, 2011).

These factors include inadequate maintenance and repair, insufficient water supply, and ineffective

Table 1: Conceptual Framework of the Study

Components	Elements	Explanation
Inputs	• Irrigation Structures	Physical and human resources introduced into the irrigation scheme.
	• Maintenance Practices	
	• Farmer Participation	
	• Water Conveyance	
Processes	• Operation & Maintenance (O&M)	Activities that transform inputs into performance outcomes.
	• Farmer Feedback Collection	
	• Physical Integrity Index (PII)	
	• Reliability Index (RI)	
Indicators	• Maintenance Effectiveness Index (MEI)	Measurable criteria used to assess system condition and performance.
	• Farmer Satisfaction Index (FSI)	
	• CMPF (Correlation between Maintenance and Functionality)	
	• Correlation between Commanded Area and Yield	
Correlations	• Operational Functionality	Statistical analyses to determine relationships between system performance factors and agricultural productivity.
	• Improved Water Distribution	
	• Enhanced Farmer Satisfaction	
	• Increased Crop Yield	
Outputs	• Sustainable Irrigation Scheme Performance	Observable results of effective inputs and processes, representing the system's performance.
	• Informed Policy and Intervention Strategies	
Outcome/Impact	• Long-term implications of the outputs, contributing to improved irrigation	Long-term implications of the outputs, contributing to improved irrigation governance and agricultural productivity.
	• and governance and agricultural productivity.	

management practices (Lefore et al., 2019). Infrastructure deteriorates because it's not well taken care of, causing water to be lost and making things less efficient. Hence, not having enough water, especially when the climate is unpredictable, can create problems with farmers not having enough water all the time. Poor management, such as failing

to schedule when water is available and not supervising how it is distributed, exacerbates the scheme's condition.

Furthermore, a lack of beneficiary consultation and participation in the planning and implementation process has been identified as a major administrative problem in the irrigation scheme (Yami et al., 2013).

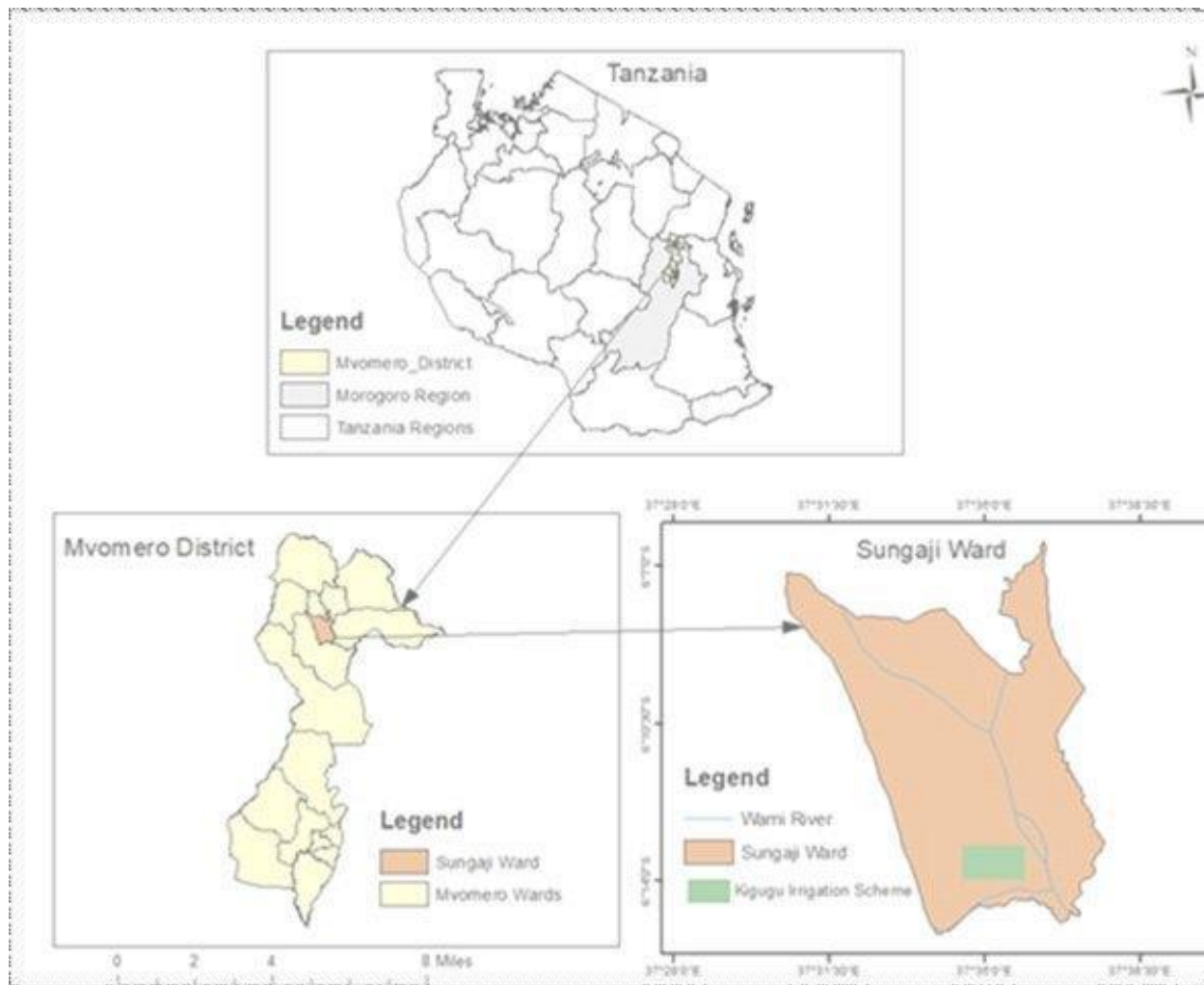


Figure 1: Location map of the study area

Efforts to address the problem of poor performance of irrigation structures have been made globally, with a focus on improving agricultural productivity and food security (FAO, 2012). These efforts typically involve initiatives aimed at enhancing infrastructure maintenance and repair, implementing more efficient water management practices, and promoting community participation in irrigation scheme development and management (Yami et al., 2013).

Globally, there has been a push for increased investment in irrigation infrastructure, aiming to modernise and expand existing irrigation systems (Harmon, 2023). This includes upgrading canals, improving reservoirs, and implementing technologies such as automated control systems to optimise water distribution.

Tanzania has a potential irrigable area of 29.4 million ha, of which only 2.4% are under irrigation. The current irrigable area is a sum of small areas developed from the total number of 2,773 irrigated schemes, of which 1,691 schemes with 419,067 ha are traditional and 1,082 schemes with 308,213.6 ha are improved (The Citizen, May 24, 2022). Most irrigation projects are facing low Water-Use Efficiency (WUE) challenges. Despite the region's low WUE values, farmers may be able to increase WUE by implementing tried-and-true water and agronomic management techniques (Silungwe et al., 2019). A lot of irrigation systems show signs of failure in comparison to expected benefits. On the other hand, the schemes can be improved through rehabilitation (Mchelle, 2011). Due to the shortage of water, irrigation water prices for farmer-managed

irrigation systems should be identified to enhance WUE (Tarimo et al., 1998).

Efficiency in performance is perceived to be achieved by improved irrigation schemes; however, this can be Kigugu irrigation scheme has an area of 800ha with an irrigation network, of which 600ha are used for paddy production. The scheme was registered by the National Irrigation Commission (NIRC) of Tanzania as an irrigator's association in 2014 with a total of 173 farmers, 111 males and 62 females (TANRICE, 2018). A total of about 1.9 billion Tanzanian shillings were used to rehabilitate

2 Materials and Methods

2.1 Description of the Study Area

The study was conducted at the Kigugu farmers-managed irrigation scheme in the Mvomero district, Morogoro Region, Tanzania (Figure 1). The scheme is among a few farmer-based schemes that were recently rehabilitated.

The entire area of the project is 800ha, located at latitudes 6°13'50'' and 6°15'15'' and longitudes 37°34'40'' and 37°33'40''. Two major

Table 2: Structures Performance Indicators

Canal's name	Count of all Structures	Count of active Structures	The number of poor structures	PSI (%)
SC.3	16	14	2	87.5
SC.4	16	13	3	81.25
Overall	42		5	11.9

the intake, and a lined main canal of 1,150 metres, as well as a remaining unlined main canal of 2,880 metres, and secondary canals number 1-4, about 3,515 metres long in total, were lined (Makutika, 2021).

The main objective of this study is to evaluate the performance of the Kigugu Irrigation Scheme in Mvomero District, Tanzania, by assessing the physical condition, maintenance effectiveness, operational reliability, and user satisfaction of the irrigation structures. This research addresses a critical knowledge gap by empirically demonstrating how the physical condition and reliability of irrigation structures directly impact user satisfaction and agricultural productivity. As such, it offers valuable insights for irrigation managers, policymakers, and development partners interested in improving irrigation scheme sustainability and effectiveness, particularly in sub-Saharan Africa.

streams, namely Chazi and Kigugu, flow through the study area, originating from the slopes of the south Nguru Mountains at elevations of 1840 and 1340 m above sea level, respectively. The study area has a mean temperature of 24.95°C. Paddy is grown in two seasons: the dry season from October to December and the wet season from March to May. Rainfall starts in October and increases until May, with a yearly total rainfall ranging from 700 to 1600 mm (Aseru et al. 2021). Aseru et al. (2021) conducted research on a system of rice intensification (SRI) in Mkindo village, which is very close to Kigugu irrigation. The study area's soils are sandy clay loam with a pH of 5.54, an electrical conductivity of 87.7 S/cm, total nitrogen, and organic carbon of 0.09% and 1.26%, respectively. These soils are suitable for paddy cultivation due to their promotion of root growth, aeration, water infiltration, nutrient retention, and drainage.

2.2 Experimental Design and Layout

The study analysed water distribution structures in the upper, middle, and tail sections of the canals as

suggested by Hager *et al.* (1992). In the Kigugu irrigation scheme, there were 62 registered farmers in the upper section, 61 in the middle section, and another 61 in the tail section. The study utilised various structures, including water distribution boxes (DBs) numbered 1–20, secondary canals (SCs) numbered 1–4, and culverts numbered 1–10.

2.3 Data Collection

The study focused on collecting comprehensive data related to irrigation structures performance, evaluation of irrigation performance using key indices: Poor Structure Index (PSI), Physical Integrity Index (PII), Reliability Index (RI), Maintenance Effectiveness Index (MEI).

2.3.1 Assessing the Conditions and Functionality of Irrigation Structures

A structured interview questionnaire was developed, and a representative sample of 184 farmers was selected. Informed consent was obtained before the interview, and face-to-face interviews were conducted to gather qualitative and quantitative data. Specific questions included satisfaction, issues, crop yields, reliability, and effectiveness of water

historical yields, discharge, and sampling representative points.

2.4 Data Analysis

2.4.1 Analysis of the Conditions and Functionality of Irrigation Structures

Irrigation structures were analysed using visual inspections, reviewing maintenance records, farmer interviews, and quantitative metrics to assess their physical integrity, reliability, and correlations between maintenance practices and system functionality, as proposed by Beyer *et al.* (2016). The analysis provided a comprehensive overview of the infrastructure's strengths and weaknesses, offering insights for improvement strategies.

2.4.1.1 Poor Structure Index

Nelson (2001) advised using the Poor Structure Index (PSI) indicator when assessing structures in programmes operated by associations or cooperatives, such as water users' associations or irrigators' cooperatives. The same approach was used in this study.

$$CMPF = \frac{\text{Correlation coefficient between maintenance efforts and system functionality}}{\text{Number of maintenance parameters considered}} \quad (6)$$

distribution structures and culverts. Maintenance practices were also assessed. Hypothetical scenarios and examples were presented to understand farmers' reactions. Documentation was done by taking notes and allowing follow-up questions based on responses.

The structures were categorised into DB 1, CULVERT1, CULVERT2, CULVERT3, CULVERT4, CULVERT5, CULVERT6, CULVERT7, DB9, & CULVERT8, DB10, DB11 & CULVERT9, DB12, DB13, DB14, DB15, DB16, DB17, DB18, DB19, DB20, and CULVERT10.

2.3.2 Analysing the Impact of Irrigation Structures on Crop Yield

The data collection process involved identifying secondary canals, design discharge, command area,

$$PSI\% = \frac{\text{Number of working structures}}{\text{Total number of structures}} \quad (1)$$

(1)

Where: PSI (%)

0–20% Indicates that majority of structures are in good working condition

21–50% indicates that considerable number of structures require attention

>50% indicates majority of structures are in poor or non-functional condition

2.4.1.2 Physical Integrity Index (PII)

The Physical Integrity Index (PII) is a crucial metric for evaluating the overall physical condition of

irrigation structures (Lalonde & Prince, 2003). It is calculated using the formula:

$$PII = \frac{\text{Number of structurally sound components}}{\text{Total number of components}} \quad (2)$$

Where: PII measures the structural soundness of irrigation components (Lalonde & Prince 2003; FAO 2002).

PII (%)	Performance Interpretation	Category
>80%	High Integrity	Most components are structurally sound
60–80%	Moderate Integrity	Some deterioration, but generally functional
<60%	Low Integrity	Widespread structural degradation

This index evaluated the overall physical condition of the irrigation structures based on visual inspections. It considered the proportion of components that were structurally sound.

2.4.1.3 Reliability Index (RI)

The Reliability Index (RI) is a crucial metric used to assess the operational performance of irrigation structures (Lalonde & Prince, 2003). Its calculation is based on the formula:

$$\text{RI} = \frac{\text{Total time of observation}}{\text{Total time of observation}} \quad (3)$$

Where:

>90%	shows highly reliable	(Near-continuous service, minimal breakdowns)
70–90%	shows moderately reliable	(Occasional interruptions in service)
<70%	indicates Unreliable	(Frequent failures affecting irrigation operations)

Lalonde & Prince (2003); Kloezen & Garcés-Restrepo (1998).

The reliability index measures the percentage of time the irrigation structures were operational over the observed period, providing insights into their reliability.

2.4.1.4 Maintenance Effectiveness Index (MEI)

The Maintenance Effectiveness Index (MEI) is a key metric used for evaluating the effectiveness of maintenance practices applied to irrigation structures (Lavy *et al.*, 2003). It is calculated using the formula,

$$MEI = \frac{\text{Number of satisfied farmers}}{\text{Total number of interviewed farmers}} \times 10 \quad (4)$$

This index assesses the effectiveness of maintenance practices by calculating the percentage of reported issues that have been successfully addressed.

2.4.1.5 Farmer Satisfaction Index (FSI)

The Farmer Satisfaction Index (FSI) plays a crucial role in assessing the satisfaction level of farmers regarding irrigation structures (Bekele, 2021). The index is defined by the formula:

$$FSI = \frac{\text{Number of satisfied farmers}}{\text{Total number of interviewed farmers}} \times 100 \quad (5)$$

The Farmer Satisfaction Index gauges the satisfaction level of farmers based on interviews, reflecting the perceived functionality and benefits of the irrigation structures.

2.4.1.6 Correlation between Maintenance Practices and Functionality (CMPF)

In 2021, de Souza *et al.*, (2021) introduced the CMPF index, representing a key metric that assesses the statistical correlation between maintenance practices and the overall functionality of irrigation systems.

This index assesses the statistical correlation between maintenance practices and the overall functionality of the irrigation system, providing insights into the effectiveness of maintenance efforts. To deal with

CMPF, six maintenance parameters for the study were used as follows:

a) Frequency of Maintenance: How often

Maintenance activities were conducted on each irrigation structure?

b) Type of Maintenance: The nature of maintenance activities (i.e., preventive, corrective, or predictive).

c) Response Time: The time taken to respond to reported issues or problems with the irrigation structure.

d) Repair Time: The time taken to complete repairs on the irrigation structure.

e) Quality of Repairs: The effectiveness and durability of repairs conducted.

f) Water Use Efficiency Measures: Implementation of measures to improve water use efficiency.

2.4.1.7 Overall Condition and Functionality Index (OCFI)

The Overall Condition and Functionality Index (OCFI), as introduced by Baghayipour *et al.* (2013) offer a comprehensive measure by aggregating the scores from individual indices (PII, RI, MEI, and FSI). The formula that expresses the calculation is as follows:

$$OCFI = \frac{\text{Sum of PII, RI, MEI, and FSI}}{4} \quad (7)$$

2.4.2 Analysis of the Impact of Irrigation Structures on Crop Yield.

The study used quantitative and qualitative methodologies to analyse the impact of irrigation structures on crop yield. Correlation analysis involved collecting quantitative data on irrigation practices (surface irrigation water discharge areas) and crop yields. Equation (8) was used to compute the correlation coefficient. Positive correlations indicate increased variables; negative correlations indicate decreased variables (Asuero *et al.*, 2006).

$$r = \frac{[n(\sum xy) - \sum x \sum y]}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}} \quad (8)$$

In the Equation provided

X represents the values of the independent variable.

y represents the values of the dependent variable.

n represents the number of data points.

xy represents the products of corresponding values of x and y .

x represents all x values.

y represents all y values.

x^2 represents squares of all x values.

y^2 represents squares of all y values.

r represents the Pearson correlation coefficient, which measures the strength and direction of the linear relationship between x and y .

3 Results and Discussion

3.1 The Current Condition and Functionality of Kigugu Irrigation Structures

3.1.1 The Current Condition of Kigugu Irrigation Structures

Results in Table 1 show that in 2023, the irrigation system had 85.7% working structures, two maintenance occurrences, and 12% water losses. These metrics indicate a high level of operational functionality but also highlight the need for attention to maintenance. Strategies to mitigate water losses are crucial for enhanced efficiency and sustainability. The percent of irrigation structures that are operational indicates that a significant portion of the system is effectively delivering water. The system has only two reported maintenance occurrences, suggesting minimal intervention. Additionally, 12% of the water is not reaching its intended destination, indicating the need for improved water use efficiency and sustainability. In comparison to similar irrigation schemes, such as Igomelo and Dakawa (Makaka *et al.*, 2020; Mchelle *et al.*, 2011), our findings highlight both commonalities and distinctions. The percentage of operational irrigation structures in our study aligns with the operational efficiency observed in Igomelo

(Makaka *et al.*, 2020). Moreover, the study showed a 12% water loss, emphasising the imperative for improved water use efficiency and sustainability.

comparison, these findings agree with Makaka *et al.* (2020) and Michelle *et al.* (2011) in emphasising the importance of maintaining irrigation structures for

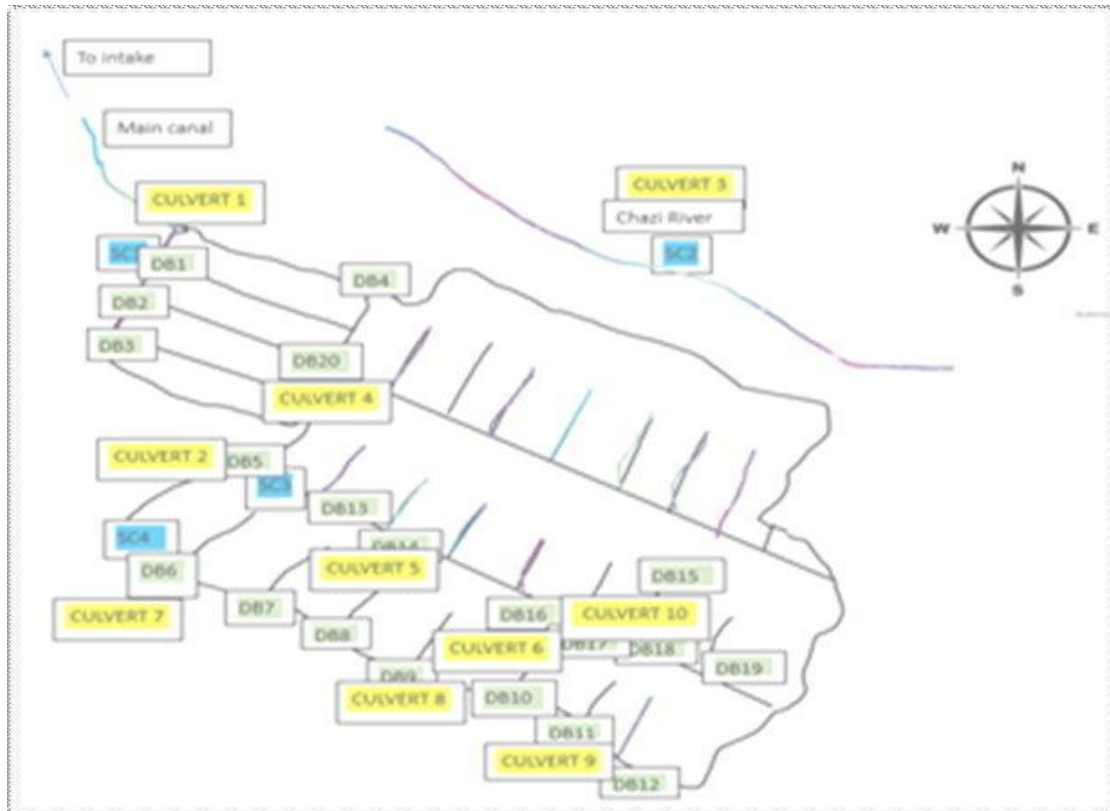


Figure 2: Number of structures

Makaka *et al.* (2020) and Mchelle *et al.* (2011) raised concerns about both Igomelo and Dakawa irrigation schemes and highlighted a broader need for implementing sustainable water management practices across irrigation schemes.

3.1.2 Poor Structure Index (PSI)

Table 2 presents results on the structural performance indicators of various canals in the irrigation system. Canal SC.1 has 10 active structures and a Poor Structure Index (PSI) of 100%, indicating optimal functioning. The Canal SC.2 has no structures, indicating no issues because the canal was not lined, although water is passing through. Canal SC.3 has 16 structures and an 88% PSI, indicating room for improvement to attain 100%. The same applies to canal SC.4, which has 16 structures: 13 active and 3 poor, with an 81.25% indicating a need for maintenance. The PSI serves as a useful metric for assessing the overall functionality of each canal. In

optimal functionality. The observed variations in PSI levels

across canals echo the need for consistent and effective maintenance practices, supporting the broader consensus in the irrigation management literature. The PSI not only provides insights into the current state of structures but also serves as a proactive tool for identifying areas that require attention and improvement.

3.1.3 Reliability Index (RI)

The findings presented in Table 3 indicate that the reliability index (RI) measured the percentage of time the irrigation structures were operational during the study. Table 3 presents the reliability index (RI)

Table 3: Reliability Index for Irrigation Structures in Kigugu Irrigation Scheme

S/N	Description	Structurally Sound Components	Total Uptime (hours)	Total Time of Observation (hours)	Reliability Index (RI)
1	DB 1	√	2200	2880	76.38
2	CULVERT1	√	2400	2880	83.33
3	CULVERT2	√	2300	2880	79.86
4	DB2	√	2000	2880	69.44
5	DB3	√	1500	2880	52.08
6	CULVERT3	√	2400	2880	83.33
7	DB4	√	2500	2880	86.8
8	CULVERT4	√	2700	2880	93.75
9	DB5	√	2700	2880	93.75
10	CULVERT5	√	2000	2880	69.44
11	DB6	√	2800	2880	97.22
12	DB7	×	2800	2880	97.22
13	DB8	√	2800	2880	97.22
14	CULVERT6	√	2200	2880	76.38
15	CULVERT7	√	2200	2880	76.38
16	DB9 & CULVERT 8	√	2700	2880	93.75
17	DB 10	√	2780	2880	96.52
18	DB 11 & CULVERT9	×	2800	2880	97.22

results for various irrigation structures in the Kigugu Irrigation Scheme. The RI measures the percentage of

time these structures were operational during the observed period. The reliability index (RI) of the

Table 4: Maintenance Effectiveness Index (MEI) for Irrigation Structures

S/N	Description	Number of Satisfied Farmers	Total Number of Interviewed Farmers	Maintenance Effectiveness Index (MEI)
1	DB 1	45	184	24.45
2	CULVERT1	50	184	27.17
3	CULVERT2	30	184	16.3
4	DB2	55	184	29.89
5	DB3	45	184	24.45
6	CULVERT3	38	184	20.65
7	DB4	60	184	32.6
8	CULVERT4	58	184	31.52
9	DB5	54	184	29.34
10	CULVERT5	59	184	32.06
11	DB6	56	184	30.43
12	DB7	28	184	15.21
13	DB8	48	184	26.08
14	CULVERT6	53	184	28.8
15	CULVERT7	60	184	32.6
16	DB9 & CULVERT 8	65	184	35.32
17	DB 10	52	184	28.26
18	DB 11 & CULVERT9	12	184	6.52
19	DB12	62	184	33.69
20	DB13	57	184	30.97
21	DB14	13	184	7.06
22	DB15	48	184	26.08
23	DB16	47	184	25.54
24	DB17	49	184	26.63
25	DB18	58	184	31.52
26	DB19	59	184	32.06
27	DB20	63	184	34.23
28	CULVERT10	60	184	32.6
Overall				26.85

irrigation structures in the Kigugu Irrigation Scheme

Table 5: Farmer Satisfaction Index (FSI) calculations

S/N	Description	Number of Satisfied Farmers	Total Number of Interviewed Farmers	Farmer Satisfaction Index (FSI)
1	DB 1	45	184	24.45
2	CULVERT1	50	184	27.17
3	CULVERT2	30	184	16.3
4	DB2	55	184	29.89
5	DB3	45	184	24.45
6	CULVERT3	38	184	20.65
7	DB4	60	184	32.6
8	CULVERT4	58	184	31.52
9	DB5	54	184	29.34
10	CULVERT5	59	184	32.06
11	DB6	56	184	30.43
12	DB7	28	184	15.21
13	DB8	48	184	26.08
14	CULVERT6	53	184	28.8
15	CULVERT7	60	184	32.6
16	DB9 & CULVERT 8	65	184	35.32
17	DB 10	52	184	28.26
18	DB 11 & CULVERT9	12	184	6.52
19	DB12	62	184	33.69
20	DB13	57	184	30.97
21	DB14	13	184	7.06
22	DB15	48	184	26.08
23	DB16	47	184	25.54
24	DB17	49	184	26.63
25	DB18	58	184	31.52
26	DB19	59	184	32.06
27	DB20	63	184	34.23
28	CULVERT10	60	184	32.6
Overall				26.85

varied across different components. The highest

Table 6: Correlation between Maintenance Practices and Functionality

S/ N	Structure	Frequency of Maintenance	Type of Maintenance	Hours		Quality of Repairs	Water Use Efficiency Measures	System Functionality	Correlation Coefficient	CM PF
				Response Time	Repair Time					
1	Tertiary canal	20 times/year	Preventive	2	6	Excellent	Implemented	High	0.75	0.75
2	Secondary canal	15 times/year	Corrective	4	8	Good	Not Implemented	Medium	0.6	0.6
3	Main canal	10 times/year	Predictive	3	5	Very Good	Implemented	High	0.8	0.8
Overall reliability index recorded was 97.22%, observed in multiple structures, including DB6, DB7, DB8, DB11 & CULVERT9, DB17, and DB18, indicating excellent operational performance. The lowest reliability index was 52.08%, found in DB3, suggesting significant inefficiencies in its operation. The average reliability index for all the structures was 86.47%, reflecting a generally high level of reliability across the system. These results										0.71

RI indicates the consistency and dependability of structure performance over time.

3.1.4 Maintenance Effectiveness Index (MEI)

MEI assesses the effectiveness of maintenance practices by calculating the percentage of reported issues that have been successfully addressed (Table 4), which varied from 15.21% to 35.32%. The overall MEI for the irrigation scheme is 26.85%, which is a

Table 7: Canals maintenance

Canal name	Unmaintained length (m)	Total length of canal (m)	Length that needs maintenance (%)
Main canal	150	3000	2
SC.1	50	1200	1.5
SC.2	60	1550	7.5
SC.3	95	1400	14
SC.4	85	1582	12

highlight that while most structures perform well, certain components require improvements to enhance overall system efficiency.

low value, providing insights into the overall effectiveness of maintenance activities.

MEI reflects the percentage of issues effectively resolved through maintenance. *MEI (%) Performance Category Interpretation*

>80% *Highly Effective Maintenance resolves most reported problems*

50–80% *Moderately Effective Partial*

(Bekele 2021; Yami et al. 2013).

FSI gauges user satisfaction with irrigation system performance and management.

3.1.6 Overall Condition and Functionality Index (OCFI)

Table 8: The opinions on the performance of irrigation structures

Question	Very Good	Good	Bad	Very Bad	Yes	No	I Don't Know
State the condition of Constructed irrigation infrastructures	100%	-	-	-	-	-	-
Are the main irrigation structures completed?	-	100%	-	-	-	-	-
State the status of working Irrigation infrastructures and facilities	-	-	87.50%	-	-	-	-
Has there been any rehabilitation in previous years?	-	-	-	-	100%	-	-
Is the scheme Operation Calendar in place?	-	-	-	-	100%	-	-
Is an irrigation facilities/structures maintenance plan in place?	-	-	-	-	-	12.62%	-
State the condition Average % of beneficiaries participating in O & M activities	-	-	100%	-	-	-	-

effectiveness, some unresolved issues

<50% *Ineffective Maintenance is largely unresponsive or poorly implemented*

3.1.5 Farmer Satisfaction Index (FSI)

The FSI gauges the satisfaction level of farmers FSI for individual structures (Table 5) and ranges from 6.52% to 35.32%. Also, the farmers reported a low value of 26.85% as the overall FSI for the irrigation scheme, reflecting their perceived functionality and benefits of the structures. *FSI (%)*

Performance Category Interpretation

>80% *High Satisfaction Farmers are largely content with services*

50–80% *Moderate Satisfaction Mixed experiences, with room for improvement*

<50% *Low Satisfaction General dissatisfaction among users*

The OCFI provides a comprehensive measure by aggregating the scores from individual indices RI, MEI, and FSI). The OCFI, as indicated in Tables 3, 4, and 5, for the irrigation scheme is 86.47%, reflecting the combined assessment of reliability, maintenance effectiveness, and farmer satisfaction. The OCFI provides a comprehensive measure by aggregating the scores from individual indices RI, MEI, and FSI). The OCFI, as indicated in Tables 3, 4, and 5, for the irrigation scheme is 86.47%, reflecting the combined assessment of reliability, maintenance effectiveness, and farmer satisfaction.

OCFI (%) Performance and Interpretation of Category

>80% *Good Overall system is performing effectively*

50–80% *Fair System has operational limitations*

<50% *Poor Significant issues in system functionality and management*

3.1.7 Structurally Sound Components

approach, efficient response and repair times, and excellent repair quality. The overall CMPF for the irrigation system is 0.71, indicating a positive relationship between maintenance practices and

Table 9: Discharge measurement points in secondary canals and yield

Canal name	Design	Command Area	Number of outlets	Yields (tons)	Yield per ton
	Q (m ³ /s)	(ha)			
SC. 1	0.0231	21.6	2	135	6.25
SC. 2	0.0228	88.35	5	552.18	6.24
SC. 3-1	0.0223	31.8	2	198.75	6.25
SC. 3-2	0.0205	31.8	2	198.75	6.25
SC. 3-3	0.0201	31.8	3	198.75	6.25
SC. 4-1	0.019	43.89	2	274.31	6.24
SC. 4-2	0.0185	43.89	3	274.31	6.24

The presence of structurally sound components in each structure ensures the physical integrity of the irrigation system. According to Table 3, all structures are in good condition. Table 3 shows structures in the Kigugu Irrigation Scheme with structurally sound components. Most structures are in good condition, while DB7, DB11, and CULVERT9 and DB14 may require further inspections to identify maintenance needs.

PII measures the structural soundness of irrigation components.

3.1.8 Correlation between Maintenance Practices and Functionality (CMPF)

The results presented in Table 6 provide a detailed overview of various maintenance parameters for different canal structures within the irrigation system. The study reveals a strong correlation between maintenance practices and system functionality in three irrigation canals. The tertiary canal has a high level of functionality due to frequent preventive maintenance, prompt response time, and excellent repairs. The secondary canal has moderate functionality, but the use of corrective maintenance and longer repair times negatively impact overall functionality. The main canal has a high level of functionality due to a predictive maintenance

system functionality.

CMPF (r) Value Correlation Strength Interpretation

Where >0.70 Strong Positive Strong link between maintenance and improved functionality

0.40–0.70 Moderate Positive Moderate impact of maintenance on performance

<0.40 Weak or No Correlation Minimal or no evident relationship

Frequency of Maintenance: The frequency of maintenance activities varied across structures, with the tertiary canal requiring the highest frequency (20 times per year), followed by the secondary canal (15 times per year), and the main canal (10 times per year). The higher frequency for the tertiary canal suggests a more proactive approach to maintenance.

Type of Maintenance: Different types of maintenance are employed for each structure. The tertiary canal undergoes preventive maintenance, emphasising a proactive strategy to prevent issues. The secondary canal involves corrective maintenance, addressing identified problems, while the main canal employs predictive maintenance, aiming anticipated issues before they occur.

Response Time and Repair Time: The response time varied across structures, with the tertiary canal having the shortest response time of about 2 hours. Similarly, repair time is the shortest for the tertiary canal (6 hours) (Table 6). This indicates a swift and efficient response to reported issues in the tertiary canal. The tertiary canal had the shortest response and repair times, indicating prompt and effective resolution of reported issues, likely contributing to its lower MEI.

Quality of Repairs: The quality of repairs is assessed differently for each structure, with the tertiary canal being rated as "excellent," the secondary canal as "good," and the main canal as "very good" (Table 6). This suggests varying levels of effectiveness in the repair processes, with the tertiary canal demonstrating particularly high-quality repairs. Differences in repair times between the canals may stem from variations in repair quality. The tertiary canal received an "excellent" rating for repairs, while the secondary canal was rated "good," and the main canal was rated "very good." This indicates varying levels of effectiveness in repair processes, with the tertiary canal ex Water Use Efficiency Measures: The quality of repairs is assessed differently for each structure, with the tertiary canal being rated as "excellent," the secondary canal as "good," and the main canal as "very good" (Table 6). **Habiting System Functionality:** The overall system functionality is rated as "high" for the tertiary and main canals and "medium" for the secondary canal (Table 6). This aligns with the maintenance strategies employed, suggesting that proactive maintenance correlates with higher system functionality. Particularly high-quality repairs.

Correlation Coefficient and CMPF: The correlation coefficient and the CMPF index are provided for each structure (Table 6). The tertiary canal demonstrates a high correlation (0.75), while the secondary and main canals show medium to high correlations (0.6 and 0.8, respectively). These values indicate the statistical correlation between maintenance efforts and system functionality. The Main Canal has a small portion of unmaintained length, accounting for only 2% of its total length. SC.1 has a good overall maintenance status, with only

1.5% of its length requiring maintenance. SC.2 has a higher percentage of unmaintained length, SC.3 has the highest percentage, and SC.4 has a moderate level of maintenance, falling between SC.2 and SC.3.

3.1.9 Community Opinions on the Performance of Irrigation Structures

Table 8 presents the understanding of scheme leaders and an irrigation technician, revealing their experiences and opinions on irrigation practices. This comprehensive dataset contributes to a deeper understanding of this critical field. The study shows that a majority of respondents (100%) are satisfied with the condition of their constructed irrigation infrastructure. They also confirm that the main structures are complete, indicating successful implementation. The majority (87.5%) of respondents believe the working infrastructure and facilities are in good condition. According to Appendix 1, all respondents have undertaken rehabilitation work in the past, demonstrating commitment to long-term sustainability. They also confirm the existence of an operation calendar for the irrigation scheme, a maintenance plan for the facilities, and a positive percentage of beneficiaries participating in operation and maintenance activities, indicating high community involvement and collaboration. Furthermore, the Participatory Rural Appraisal Questionnaire, as per Appendix 2, gathered data from 184 farmers (105 males, 79 females). Farming dominated occupations (143 farmers), with incomes mainly between \$50 and \$440. Paddy was the primary crop. Water scarcity affected all farmers, influencing irrigation schedules.

3.2 The Impact of Irrigation Structures on Crop Yield

Correlation Coefficient between "Command Area" and "Yields" was found to be 0.969. This correlation coefficient indicates a strong positive correlation between the commanded area and yields for the given canals. Table 9 presents insights into the relationship between discharge measurements in secondary canals and crop yields. Design discharge

varies across canals, reflecting diverse water-carrying capacities. Canals serve a specific total land area, known as the command area, and determine water distribution based on the number of outlets they possess. Total yields ranged from 135 to 552.18 metric tons, and yield tons per hectare measures efficiency in converting water resources to crop

4. Conclusions and Recommendations

This study assessed the performance of irrigation structures within the Kigugu Irrigation Scheme in Tanzania using a set of scientifically established indices—PSI, PII, RI, MEI, FSI, CMPF, and the OCFI. The findings revealed that while a majority of structures were operational (85.7%), significant challenges remain in terms of maintenance effectiveness and farmer satisfaction, both scoring as low as 26.85%.

By applying these indices and establishing benchmark thresholds for each, the study provides a replicable framework for evaluating the performance of smallholder irrigation systems. More importantly, this study quantifies the link between structural reliability and crop yield, providing empirical evidence that can guide targeted maintenance interventions and infrastructure upgrades in similar schemes.

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APPENDICES

Appendix 1: Irrigation Infrastructure Assessment

Please indicate your response by selecting the appropriate option:

1. State the condition of Constructed irrigation infrastructures:

- Very Good
- Good
- Bad

• Very Bad • I don't know	Appendix 2: Farmers Questionnaire results
2. Are the main irrigation structures completed?	Results of Participatory Rural Appraisal Questionnaire:
• 100% • I don't know	1.0 INTRODUCTION
3. State the status of working irrigation infrastructures and facilities:	1.1 Total Respondents: 184
• Very Good • Good • Bad • Very Bad • I don't know	1.2 Average Age: 38 years
4. Has there been any rehabilitation in previous years?	1.3 Gender Distribution:
• Yes • No • I don't know	• Male: 105 • Female: 79
5. Is the scheme Operation Calendar in place?	1.4 Marital Status: a. Married: 94 b. Single: 30 c. Divorced: 40 d. Widowed: 20
• Yes • No • I don't know	1.5 Educational Attainment: a. No formal education: 45 b. Primary education: 87 c. Secondary education: 35 d. technical education: 12 e. University/Diploma level: 5 f. Others: 184
6. Is an irrigation facilities/structures maintenance plan in place?	1.6 Ethnicity Information Noted.
• Yes • No • I don't know	1.7 Religious Affiliation:
7. State the condition Average % of beneficiaries participating in O & M activities:	1. Christian: 89
• Very Good • Good • Bad • Very Bad • I don't know	2. Muslim: 95
	3. Pagan: Not specified
	4. Others: Not specified
	1.8 Occupational Distribution: a. Farming: 143 b. Public Sector Employment: 10 c. Private Sector Employment: 12 d. Own Business: 19 e. Others: Not specified
	1.9 Annual Income Ranges:
	• Less than \$50: 0 • Between \$50-\$220: 98 • Between \$220-\$440: 71 • Between \$440-\$1300: 15 • Above \$1300: Not specified
	2.0 IRRIGATION ENGAGEMENT
	2.1 Duration of Membership in the Irrigation Scheme:
	• Less than 2 years: 23 • Between 2 and 5 years: 72

- More than 5 years: 89
- Others: Not specified

3.0 FARMING PRACTICES

3.1 Experience in Irrigation Agriculture:

Crop	Food Security	Income	Income and Food	High Yield	Non
Maize					
Paddy	24		98	62	
Beans					
Vegetables			2		
Tomatoes					

- Less than 5 years: 15
- 5 – 10 years: 74
- More than 10 years: 95

2.0 LAND UTILIZATION

2.1 Number of Cultivated Farm Plots under Irrigation: a. One: 70 b. Two: 64 c. Three: 21 d. Four: 17 e. More than five: 12

2.2 Size of Farm Plots: a. 0.5 acres: 23 b. 1 acre: 71 c. 2 acres: 64 d. 3 acres: 17 e. 4 acres: 9 f. More than 5 acres: Not specified

2.3 Farm Plot Locations in Relation to the Scheme:

1. Head: 62
2. Middle: 61
3. Tail: 61

2.4 Cultivated Crops:

- Paddy: 182
- Maize: Not specified
- Beans: Not specified
- Sunflower: Not specified
- Onions: Not specified
- Vegetables: 2
- Tomatoes: Not specified

2.5 Crop Yields and Income:

- Water Distribution Committee: 184

3.0 IRRIGATION BASELINE DATA

- An individual appointed by the Association

3.1 Types of Irrigation Methods: a. Furrow b. Check Basin c. Check Border Strips d. Wild/Uncontrolled Flooding e. Others (Specify)

4.4 Involvement in Formulating Irrigation Schedules

3.2 Factors Influencing Crop Selection for Irrigation:

- In a General Meeting of all irrigators: 184
- Informed by the Ward Extension Officer
- Informed by the individual who distributes water

3.4 Reasons for Cultivating Specific Crops

Reasons for Growing Crops

- Informed by the Water Distribution Committee Members

4. Duties of Irrigators' Association

- Not involved at all

4.1 Formation of Irrigators' Association

4.5 Factors Considered in Preparing Schedules

- It was our own initiative
- Through advice and technical assistance from the district
- Through advice and technical assistance from

- Type of crops grown in the area
- Availability of water in the main canal
- Reduction of conflicts among irrigators: 184

S/ N	Crop	Farm Plot Size (ha)	Crop Yield (kg)	Yield (kg/ha)	Pri ce per kg (\$)	Amo unt of Money (\$)
1	Paddy	1	6,200 .00	6,200 .00	0.8	4,960 .00
2	Maize					
3	Beans					
4	Sunflower					
5	Onions					
	Tomat					

an NGO

- Forced to formulate it by the Government: 184

- Imposed by the executing agency
- Nature of the soil in the area
- Do not know

4.3 Responsibility for Irrigation Schedule

4.6 Existence of Fixed Irrigation Rotation

- District Irrigation Specialist
- Ward Extension Officer

- Yes: 174
- No: 10

- If YES, rotation interval:
- Seven days
- Five days
- Three days: 174
- Eight days
- Others (Specify)
- If NO, how is it practiced?

• According to water availability in the main canal

- Depending on an individual request: 10
- Depending on the feeling of the water distribution person
- Order of the Ward Extension Officer
- Depending on the decision of the water distribution committee

- Others (Specify)

4.7 Satisfaction with Irrigation Scheduling

- Very Good
- Good: 174
- Moderate
- Bad
- Very bad

4.8 Dependability of Irrigation Scheduling

- Very High: 174
- High
- Satisfactory
- Low
- Very Low

4.9 Equality in Water Allocation to Crops

- YES: 174
- NO: 10
- If NO, why?
- Some farmers at the lower farms divert water illegally

4.10 Consistency in Water Allocation Across Growth Stages

- YES: 174
- NO: 10

4.10 Stage of Increased Irrigation Water Allocation

If NO, at what stage do you give more irrigation water to your crop?

- Germination stage
- Vegetative (growing stage): 10
- Flowering stage
- Fruiting stage
- Others (Specify)

4.11 Decision Making for Irrigation Timing

How do you decide when to irrigate?

- Looking at the dryness of the soil: 184
- Looking at the color of the leaves
- Measuring soil moisture
- Advised by an Extension Officer
- Other method (Specify)

4.12 Irrigation Water Scarcity

Do you experience irrigation water scarcity during the rainy season?

- YES
- NO: 184
- If YES, what is your coping strategy?
- Do not irrigate the already planted crop
- Irrigate once
- Use whatever available water
- Increase irrigation frequency
- Others (Specify)

Do you experience irrigation water scarcity during the dry season?

- YES: 184
- NO

- If YES, what is your coping strategy?
- Do not irrigate the already planted crop
- Irrigate once
- Use whatever amount of available water
- Increase irrigation frequency: 184
- Reduce the amount of irrigation water to be applied

- Others (Specify)

4.13 Assessment of Water Application

How do you say that you have supplied the right amount of water to the crop?

- By having ponded water in the basin or furrow: 150
- Simply by guessing: 20
- Inserting a piece of stick into the ground: 14
- Seeking advice from friends who practice irrigation
- Others (Specify)

4.15 Evaluation of Irrigators' Association Operations

How do you find the operations of the Irrigators' Association?

- Very Good: 9
- Good: 50
- Moderate: 125
- Bad
- Very bad

4.16 Problems in Water Distribution

Are there problems in water distributions within the scheme?

- YES: 184
- NO
- If YES, What are the causes of the problem?
- Favoritism caused by the Water Distribution Committee

- Scarcity of irrigation water: 176
- The gate rider is not punctual
- Individual farmers stealing water when it is not their turn: 8

- All the above
- Others (Specify)

4.21 Frequency of Communication

How often is the information communicated?

- Daily
- Weekly
- Monthly: 15
- After three months
- Yearly: 169
- Others (Specify)

4.24 Fertilizer Usage

Do you use fertilizers in your farms?

- YES: 184
- NO

How much fertilizer do you use per season?

- Less than 50kg per acre
- More than 50kg per acre: 184
- More than 100kg per acre

4.26 Awareness of Fertilizer Impact

Do you know that fertilizers are harmful to the soil?

- YES
- NO: 184

4.31 Canal and Distribution Structure Maintenance

How often do you clean your canals and the distribution structures?

- Daily
- Weekly
- Monthly
- After three months
- Yearly

- Others (Specify)

4.37 Attendance of Irrigation Water Management Training

Have you attended any irrigation water management training?

- YES: 162
- NO: 22